1145 Issued April 17, 1909.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 208.

A. C. TRUE, Director.

# THE INFLUENCE OF MUSCULAR AND MENTAL WORK ON METABOLISM

AND

# THE EFFICIENCY OF THE HUMAN BODY AS A MACHINE.

BY

FRANCIS G. BENEDICT, Ph. D.,
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## OFFICE OF EXPERIMENT STATIONS.

### NUTRITION INVESTIGATIONS.

A. C. True, D. Sc., *Director.*
E. W. Allen, Ph. D., *Assistant Director and Editor of Experiment Station Record.*
C. F. Langworthy, Ph. D., *Expert in Nutrition.*
R. D. Milner, Ph. B., *Assistant in Nutrition.*

# LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
*Washington, D. C., January 4, 1909.*

Sir: I have the honor to transmit herewith, and to recommend for publication as Bulletin 208 of this Office, a report of 19 experiments on the effects of muscular work on metabolism and the efficiency of the human body as a machine, and 44 experiments on the effects of mental work on metabolism.

These investigations were carried on at Wesleyan University, Middletown, Conn., in cooperation with this Department by F. G. Benedict, Ph. D., who was then professor of chemistry at Wesleyan University, and is now director of the Nutrition Laboratory of the Carnegie Institution of Washington, at Boston, Mass., and T. M. Carpenter, B. S., who is associated with Doctor Benedict, and the work forms a part of the investigations which have been carried on by the Department for the purpose of studying the fundamental laws of nutrition and various problems which depend upon them.

The results which were obtained furnish accurate and interesting data regarding the extent of the effects of muscular work on metabolism but, even with the delicate methods followed, do not indicate that mental work affects in any appreciable way the indexes of metabolism which were studied.

As regards the effectiveness of the body as a machine, experimental evidence shows that body efficiency is 20 per cent; that is, for every calorie of muscular work produced by the body a total of 5 calories of energy is expended.

Acknowledgment should be made of the service rendered in these experiments by Mr. N. Butler, a professional bicyclist, who volunteered to act as subject of experiments on muscular work and body efficiency.

The courtesy of the members of the faculty and students of Wesleyan University who cooperated in the experiments on the effects of mental work should also be acknowledged.

Respectfully,

A. C. True,
*Director.*

Hon. James Wilson,
*Secretary of Agriculture.*

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# INFLUENCE OF MUSCULAR AND MENTAL WORK ON METABOLISM AND EFFICIENCY OF THE BODY AS A MACHINE.

## MUSCULAR WORK AND BODY EFFICIENCY.

### INTRODUCTION.

The marked and immediate influence of muscular exertion on the transformations of matter and energy in the body has long served as a subject for experimentation. The earliest experimenters were enabled to make observations on the influence of severe muscular exercise on the body functions from simple observations on the appearance of fatigue, sensible perspiration, rapid respiration and pulse rate, and loss in weight. Such superficial observations were soon supplemented by others more or less accurate regarding the amount of work that the body could do. The attempts to measure this amount of work have been numerous, and have resulted in the development of several sorts of apparatus for this purpose.

The simplest (and perhaps the earliest) device for measuring work was that of lifting a weight a given number of times. From the well-known relations of work to the weight times the height to which it is lifted, it was possible to compute in foot-pounds the amount of work performed by a man. The treadwheel, which is described by Hirn[a] and Chauveau,[b] is a device based upon the same physical principle as lifting a weight. The subject lifts his own body through varying heights, depending upon the length of time during which he walks on the treadwheel or treadmill. The introduction of the ergograph, which has been elaborated by Mosso,[c] enabled studies of particular groups of small muscles to be made with great accuracy. The ergostat, which has been introduced in recent years, particularly by Johannson[d] and Zuntz,[e] permits the bringing into play of the powerful muscles of the arm and back.

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[a] La Thermodynamique et l'Etude du Travail chez les Êtres vivants. Paris, 1887.
[b] Compt Rend. Acad. Sci. [Paris], 129 (1899), p. 249.
[c] Arch. Ital. Biol., 13 (1890), p. 123.
[d] Skand. Arch. Physiol., 11 (1901), p. 273.
[e] Arch. Physiol., 1899, Sup., p. 39.

In recent years the attempt has frequently been made to compute the amount of work performed by bicyclists during a long race. In such computations the chain, tire, and the resistance of the bicycle are taken into account.

All of these devices for determining the amount of work done are open to serious error. In the lifting of weights there is a large amount of extraneous muscular effort which must be very inefficiently applied to the weight. Then in the majority of the experiments in which weights were lifted the same subject lowered them, and the work done to counteract the force of gravity as the weight was lowered was not taken into consideration. Of the ergographs, that of Mosso has been the most used, and yet the work of lowering the weight has not been duly taken into consideration in this form of instrument. The ergograph of Hall[a] is much more satisfactory for this purpose, but is applied, at present at least, only to small groups of muscles. At Yale University Prof. Irving Fisher[b] has used Hall's cushion ergograph for the muscles of the leg and, he states, with great success.

The chief objection to the principle of the treadwheel or treadmill lies in the fact that there is no wholly satisfactory method of determining the work of forward progression, which must necessarily enter into the estimate of the work done. The method of calculating the work performed by a professional bicyclist, depending upon the resistance of the chain, tire, and air, is, we believe, most unsatisfactory, as was brought out by the data reported by Atwater, Sherman, and Carpenter.[c] A far more satisfactory and accurate method is that employed by Berg, Du Bois-Reymond, and Zuntz,[d] in which an automobile or motor cycle was used to tow a man mounted on a regular bicycle around a track at different rates of speed.

The ergostat, relying upon the muscles of the arms, must of necessity bring into play a large number of other muscles which are inefficiently applied to the point where the work is done.

## RELATION OF WORK TO TOTAL HEAT OUTPUT.

Not only have attempts been made to compute the total energy or work done by man, but numerous writers have likewise attempted to compute the ratio between the amount of work produced and the total heat output. The carbon dioxid output was used as early as 1844 by Scharling[e] as an index of the heat production and oxidation processes in general. Scharling's method of performing muscular

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[a] Experimental Physiology, W. S. Hall, 1904, p. 227.

[b] Private communication.

[c] U. S. Dept. Agr., Office of Experiment Stations Bul. 98. See also L. Zuntz, Untersuchungen über den Gaswechsel und Energieumsatz des Radfahrers. Berlin, 1899.

[d] Arch. Anat. u. Physiol., Physiol. Abt., 1904, Sup., p. 20.

[e] Ann. Chem. u. Pharm., 45 (1843), p. 214.

work was to raise and lower a heavy iron bar. During this process a marked increase in the output of carbon dioxid was noted. Zuntz and his associates in Germany, and Chauveau and Tissot in France, have determined the respiratory quotients during muscular work. From the ratios of the amounts of carbon dioxid and oxygen measured during rest and during work the authors have attempted to compute not only the amount of work done but the total energy eliminated.

The direct measurement of the heat production of man during muscular work, however, has been made possible only by means of the respiration calorimeter at Wesleyan University, Middletown, Conn. This apparatus has been in process of development for the last twelve years in connection with the nutrition investigations of this Department.

During one of the early experiments with this apparatus the subject performed a considerable amount of mechanical work by raising and lowering a weight, and on those days during which the work was performed there was a marked increase in the output of carbon dioxid over the resting value. Subsequently, in connection with further experiments in these series, an improved form of bicycle ergometer was devised in which a bicycle was so adjusted that the rear wheel pressed against the wheel attached to the armature shaft of a small dynamo. From the amount of electricity generated the amount of external muscular work performed could be computed. The method of calibrating the machine, and the description of the machine itself, has been given in detail in an earlier bulletin of this series, in an account of experiments reported by Atwater and Benedict.[a]

The inequalities of the surface of the tire, the slip, variations in tension of spring, and numerous other factors rendered the limit of error on this machine too large for the most satisfactory work, and hence a special form of bicycle ergometer was constructed in which it was attempted to eliminate in so far as possible all known errors.

The apparatus has been briefly described in several preceding publications,[b] but its detailed description, method of calibration, and the reports of the experiments made with it are here presented in detail for the first time.

## THE BICYCLE ERGOMETER.

### CONSTRUCTION.

Relying on the powerful leg muscles and the form of the bicycle to secure the greatest efficiency and longest continued sustained effort, the ergometer was constructed substantially along the lines of a modern bicycle. The rear wheel of a bicycle was replaced by a

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[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 136.

[b] U. S. Dept. Agr., Office of Experiment Stations Bul. 175; Yearbook 1904, p. 205.

copper disk 40.5 centimeters in diameter and 6 millimeters thick. This disk is mounted in such a way that it rotates freely on a ball-bearing axle. A small sprocket wheel is attached to the axle and is in turn connected in the usual manner with the large pedal sprocket wheel by means of a sprocket chain. A wooden frame surrounds the periphery of the disk, and to the upper part of the frame is attached an electro-magnet. Binding posts are attached to the magnet to connect with the electric cable leading to the observer's table, where the strength of current through the field can be regulated with great accuracy. The field of the magnet is so extended that the copper disk rotates in the center of the field with but a very small air gap between the surface of the disk and the surface of the magnet, and hence the resistance is wholly that of magnetic induction. A current of 1.25 amperes induces large eddy currents in the copper disk to such an extent that the resistance is very noticeable, and as the speed of the rotating disk increases it becomes very much heated. In the absence of a commutator the currents become short-circuited in the disk and give rise to the generation of heat. This heat is radiated from the disk into the surrounding air.

Obviously, the stronger the field of the magnet on this apparatus the greater are the currents generated in the disk and the greater is the torque. Variations in the flux density of the field are obtained by varying the strength of the current passing through the coil. By increasing the intensity of the current passing through the electro-magnet any desired degree of resistance can be obtained. The current is supplied from a storage battery of seven cells in series with a milammeter and adjustable resistance, and the current is kept constant. The resistance of the field coil rises with a rise in temperature of the coil, so that it is necessary to adjust the series resistance at the start. The resistance of the field coil is not far from 8 ohms. In general, 1.25 amperes are passed through the field, as this has been found to produce the most satisfactory torque on the disk.

To anticipate the effects of long-continued usage especial care was taken in the construction of the ergometer, and after four years' use the apparatus functionates perfectly and shows no appreciable deterioration or variation in its constants. As was stated above, the strength of the field of the magnet is an important factor in determining the amount of current induced in the disk. This depends upon several factors, the most important of which are the magnetic conductivity of the core, the number of ampere turns around the core, and the width of the air gap. The core and poles are made of the best quality of magnet iron obtainable and are wound with No. 18 single-covered copper magnet wire. The general construction of the apparatus can readily be seen in figure 1.

In the construction of the apparatus every precaution was taken with the bearings, selection of chain, and suspension of the disk

to secure the minimum friction. There is very little residual magnetism in the iron cores, and hence when the disk is rotated and no current is passed into the magnet the wheel rotates freely and for several minutes, there being no appreciable resistance.

Attached to the frame of the bicycle is a spring which presses continually against the inside of the large sprocket. As the sprocket turns, a disk of insulating material breaks an electric circuit for the greater part of the time, but for a short period in each revolution the spring comes in contact with metal and completes the circuit, and an electric current from four dry cells actuates an automatic counter on the observer's table, and thus each revolution of the

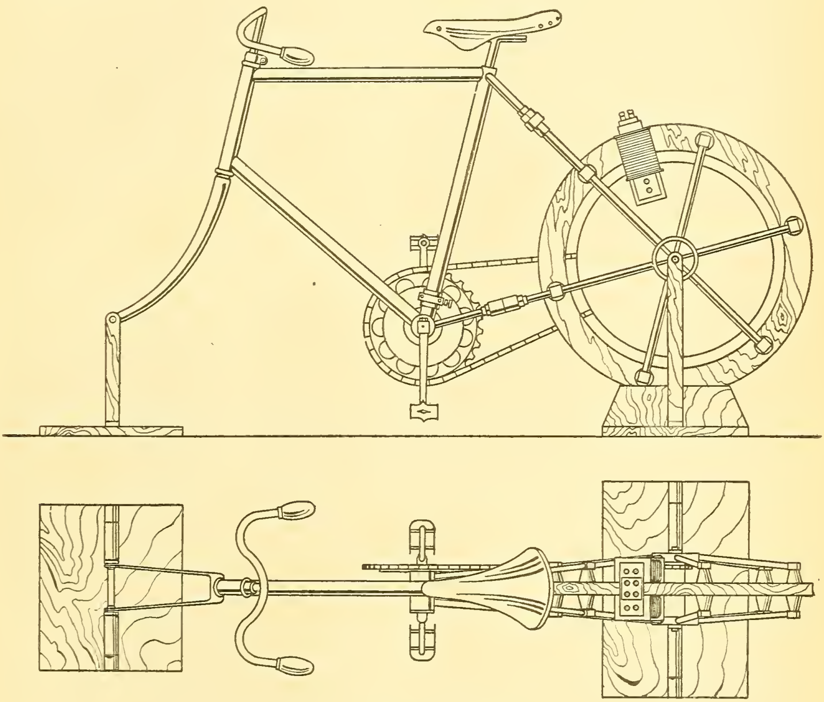

Fig. 1.—The bicycle ergometer.

pedal is recorded. As pointed out above, the degree of resistance applied to the rotating disk is dependent upon the current passing through the electric field. A large number of tests with the apparatus showed that a current of 1.25 amperes caused a degree of resistance that was considered to be hard work by most of the riders.

### PRINCIPLE OF THE ERGOMETER.

The electric brake, while frequently used in technical machines, is not in common use in scientific instruments. For a thorough understanding of the efficiency of this apparatus it is necessary to see clearly that there is no friction (in the common acceptance of the term) in this apparatus.

If a wire is passed through the fields of an electro-magnet, a difference of potential will be present at the ends of the wire, but no current will flow through it, and no energy is required to move it other than that necessary to overcome gravity. If, however, the ends of the wire are connected with each other, a current will flow through it and additional energy will be required to move it through the magnetic field. This energy will be proportional to the square of the strength of the field and directly proportional to the speed.

This may be called magnetic friction, and, according to Lentz's law, in all cases of magnetic induction the induced currents have such a direction that their reaction tends to stop the motion which produces them. If, in place of a single-wire conductor, a disk is so adjusted that it can be rotated between the poles of a magnet, the induced currents will be short-circuited in the disk as soon as generated and consequently there developed into heat. Furthermore, as in the case of the wire, the induced currents will tend to stop the motion of the rotating disk, and thus produce an effect that may be called that of an electric brake.

### METHOD OF CALIBRATING THE ERGOMETER.

The primary object of this apparatus is to measure the amount of external muscular work that a man can apply to the pedals of a bicycle ergometer. The ordinary process of calibration of such an apparatus would involve the use of some form of cradle dynamometer and the results would be obtained in terms of foot-pounds, which in turn would be converted into calories or British thermal units. For the purpose of studying the mechanical efficiency of a man, it is obviously of great advantage to measure the external muscular work in terms of calories. During his early development of this ergometer, it was suggested by Prof. W. O. Atwater that it might advantageously be calibrated by placing the whole apparatus inside the chamber of the respiration calorimeter described later.

This plan was adopted, and by means of a flexible shaft attached to the large sprocket the apparatus was driven by electric power outside the chamber at different rates of speed from 50 to 85 revolutions per minute. A current of 1.25 amperes was then passed through the electro-magnet and the heat evolved measured by the respiration calorimeter. This method of calibration has proved eminently successful, and by its use the work performed is measured in calories and the errors incident to the use of a dynamometer are eliminated.

The method of installing the ergometer in the respiration chamber for a calibration test is illustrated in figure 2.

The ergometer is placed inside of the chamber in a vertical position, with a shaft from the large sprocket wheel extending through the food aperture, and by outside connections by pulley and belt to the main shaft it can be rotated at any given speed. A current is passed

through the electro-magnet and the whole system is run for a number of hours, the heat developed being measured in the usual way by the current of water passing through the calorimeter.

In the calibration of the ergometer, about two hours are required for the calorimeter and the heat-measuring appliances to attain equilibrium. At the end of that time the heat production of the ergometer is equal to the heat absorption by the water current of the

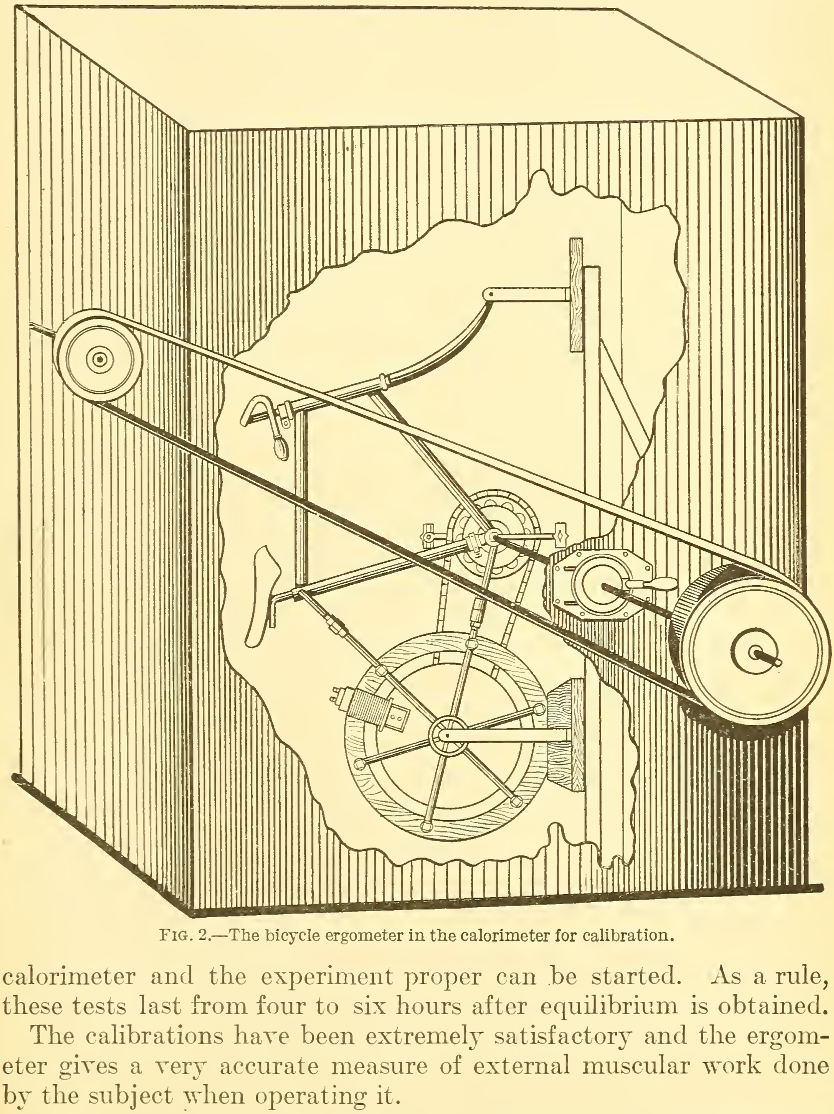

FIG. 2.—The bicycle ergometer in the calorimeter for calibration.

calorimeter and the experiment proper can be started. As a rule, these tests last from four to six hours after equilibrium is obtained.

The calibrations have been extremely satisfactory and the ergometer gives a very accurate measure of external muscular work done by the subject when operating it.

As the friction of the machine was considered to be extremely low, a test was made to measure this in calories. It was found that when running the apparatus with no current through the electro-magnet,

due precautions being taken to prevent conduction of heat out of the calorimeter through the flexible shaft, each revolution corresponded to a heat production of 0.001547 calorie, which is a direct measure of the friction.

This value includes any effect of the slight residual magnetism in the field.

As the result of a number of experiments, it was found that each revolution of the large sprocket wheel, when a current of 1.25 amperes was passing through the electro-magnet, resulted in a heat production of 0.0231 calorie. It is obvious, therefore, that to compute the external muscular work of a subject riding this ergometer it is only necessary to know the number of revolutions of the pedal, obtained from the electric counter, and in case the current through the fields is 1.25 amperes to multiply by the factor 0.0231.

## RESULTS OF ERGOMETER CALIBRATIONS.

Since the ergometer was constructed a number of calibrations have been made according to the method described in the preceding section. The results of these calibrations have been recorded chronologically in the following table:

*Heat produced in ergometer calibrations.*

| Date. | Duration of period. | | | (*a*) Heat measured. | (*b*) Corrected to $C_{20}$. | (*c*) Change of calorimeter. | (*d*) Change of temperature of absorbers. | (*e*) Heat of magnetization. | (*f*) Heat produced. | (*g*) Number of revolutions. | (*h*) Heat per revolution. | (*i*) Current. | (*j*) Number of revolutions per minute. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1903. | *h.* | *m.* | *s.* | *Calories* | *Calories* | *Calories* | *Calories* | *Calories* | *Calories* | | *Calories* | *Amp.* | |
| Oct. 5 | 6 | 17 | 6 | 772.39 | 774.24 | −3.6 | +0.60 | −68.74 | 702.50 | 29,967 | 0.0234 | 1.250 | 79 |
| 6 | 6 | 52 | 46 | 741.22 | 743.15 | −9.0 | + .29 | −53.42 | 681.02 | 30,006 | .0227 | 1.250 | 102 |
| 9 | 6 | 50 | 34 | 854.62 | 856.84 | −2.4 | − .98 | −74.74 | 778.72 | 33,554 | .0232 | 1.250 | 82 |
| 12 | 4 | 9 | 30 | 532.90 | 534.23 | ........ | − .88 | −52.88 | 480.47 | 20,837 | .0231 | 1.250 | 72 |
| 12 | 4 | 20 | 30 | 635.07 | 636.72 | ........ | +1.07 | −47.41 | 590.38 | 25,833 | .0229 | 1.250 | 99 |
| 1904. | | | | | | | | | | | | | |
| Oct. 26 | 7 | 10 | 50 | 873.05 | 874.45 | ........ | ........ | −78.59 | 795.86 | 34,158 | .0233 | 1.250 | 79 |
| Nov. 18 | 5 | 39 | 30 | 642.43 | 643.71 | +3.0 | + .57 | −61.99 | 585.29 | 25,214 | .0232 | 1.250 | 74 |
| 18 | 5 | 14 | 27 | 664.13 | 665.78 | +2.4 | +1.05 | −57.25 | 611.98 | 25,964 | .0236 | 1.250 | 83 |
| 1905. | | | | | | | | | | | | | |
| May 13 | 6 | 30 | 0 | 480.40 | 481.17 | +3.0 | ........ | −27.60 | 456.57 | 27,769 | .0164 | .800 | 71 |
| 15 | 6 | 0 | 0 | 360.54 | 361.01 | + .6 | −1.93 | −19.40 | 340.28 | 27,361 | .0124 | .700 | 76 |
| 16 | 6 | 0 | 0 | 501.07 | 502.02 | + .6 | +1.58 | −32.46 | 471.74 | 26,713 | .0176 | .900 | 74 |
| 17 | 6 | 0 | 0 | 725.30 | 726.90 | + .6 | − .82 | −65.64 | 661.04 | 29,157 | .0227 | 1.250 | 81 |
| 18 | 6 | 0 | 0 | 381.76 | 382.52 | ........ | −1.19 | −19.40 | 361.93 | 27,290 | .0133 | .700 | 76 |
| 19 | 6 | 0 | 0 | 438.28 | 439.20 | − .6 | + .99 | −25.48 | 414.11 | 26,532 | .0156 | .800 | 74 |
| 20 | 6 | 0 | 0 | 743.32 | 745.10 | + .6 | +1.21 | −65.64 | 681.27 | 29,958 | .0227 | 1.250 | 83 |
| 22 | 2 | 21 | 0 | 199.70 | 200.16 | −7.2 | + .31 | −12.71 | 180.56 | 10,654 | .0170 | .900 | 76 |
| 23 | 7 | 0 | 0 | 520.81 | 521.85 | +2.4 | − .80 | −29.72 | 493.73 | 31,586 | .0156 | .800 | 75 |
| 24 | 7 | 0 | 0 | 611.56 | 612.91 | ........ | +1.42 | −37.87 | 576.46 | 32,950 | .0175 | .900 | 78 |
| 26 | 4 | 0 | 0 | 250.74 | 251.19 | ........ | +1.29 | −12.94 | 239.54 | 19,227 | .0125 | .700 | 80 |
| 27 | 7 | 0 | 0 | 836.02 | 838.03 | −4.2 | − .62 | −76.58 | 756.63 | 32,945 | .0230 | 1.250 | 78 |
| 29 | 6 | 0 | 0 | 395.30 | 396.09 | + .6 | −1.25 | −19.40 | 376.04 | 28,899 | .0130 | .700 | 80 |
| 29 | 6 | 0 | 0 | 671.14 | 672.82 | − .6 | −1.52 | −50.46 | 620.24 | 30,035 | .0207 | 1.100 | 83 |

The table shows the date of each experiment, the period, the measured (expressed in calories), and the corrections necessary termine the exact amount of heat resulting from the rotation the

ergometer. Thus the heat as measured by the calorimeter must be corrected to the standard calorie used in all experiments thus far made with this respiration calorimeter, i. e., the amount of heat required to raise 1 kilogram of water from 19.5° to 20.5°. This is commonly expressed as the calorie at 20° or $C_{20}$.

Even with the most accurate manipulation on the part of the physical assistants, it is difficult to have an experiment so conducted that the temperature of the chamber is the same both at the beginning and at the end of the experiment. Consequently, slight corrections are necessary for the capacity of the calorimeter to store or yield heat.

The heat-absorbing system consists of a copper pipe, to which a large number of disks are soldered, to increase the heat-absorbing surface. At the beginning of the experiment the temperature of this system may be roughly assumed to be the average temperature of the ingoing and outcoming water. At the end of the experiment the average temperature of this system may be somewhat different, and hence a correction is necessary for the heat capacity of the absorbers.

Finally, in this form of bicycle ergometer it is necessary to introduce an electric current to magnetize the field of the apparatus, and this current passing through a resistance in the calorimeter generates a small amount of heat. From the strength of the current and the resistance the heat developed may be very accurately computed. This is recorded in column *e* of the table under the head of "heat of magnetization."

The actual amount of heat produced by the ergometer is given under the head of "heat produced."

The number of revolutions of the pedals was registered by the electric counter previously described and also by a mechanical counter. In each experiment the total number of revolutions is recorded. In column *h* the heat per revolution obtained by dividing the total heat production by the total number of revolutions is recorded.

The strength of current used to magnetize the field and the number of revolutions per minute are recorded in the last two columns of the table.

The results of the calibrations given in the previous table are expressed chronologically. The average results for the different strengths of current through the field are given in the following table:

*Average heat production of ergometer for currents of different strength.*

| Strength of current. | Heat per revolution of ergometer. | Strength of current. | Heat per revolution of ergometer. |
|---|---|---|---|
| *Ampere.* | *Calorie.* | *Amperes.* | *Calorie.* |
| 0.700 | 0.0128 | 1.100 | 0.0207 |
| .800 | .0156 | 1.250 | .0231 |
| .900 | .0174 | | |

In the majority of the experiments reported beyond, this latter value is used, i. e., that every revolution of the pedal, when the field of the ergometer is carrying a current of 1.25 amperes, results in the production of 0.0231 calorie of heat. An inspection of the results given in the table (p. 16) shows that the results for the magnetization at 1.25 amperes ranged from 0.0227 to 0.0236.

The results are on the whole extremely satisfactory, and we believe that the factors thus determined are well within the limit of error of physiological experimenting. The calibrations have been expressed in the form of a curve (fig. 3).

This curve shows that the heat per revolution is almost directly proportional to the strength of the current. The curve shows a sufficient number of established points to serve for the computation of the

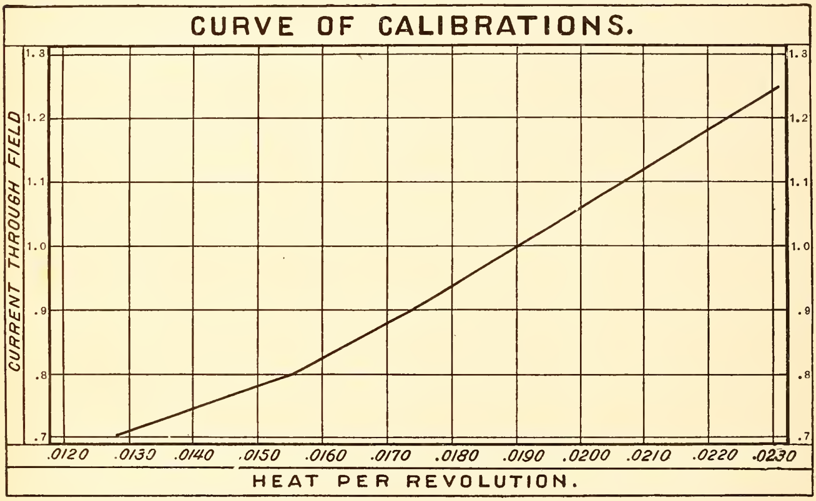


FIG. 3.—Curve of calibrations.

heat production with any strength of current through the field. For the lower currents, especially between 0.700 and 0.800 ampere, other points should be found.

An inspection of the figures in the table (p. 16) shows that, as might be expected from Lentz's law, with a given resistance, the amounts of heat developed are directly proportional to the number of revolutions of the pedals and independent of the rate of speed. Thus in the test of October 12, from 11.20 a. m. to 4.10 p. m., with 72 revolutions per minute, the heat per revolution was 0.0231 calorie, while during the second part of the test, from 6.07 p. m. to 10.27 p. m., with 99 revolutions per minute, the heat per revolution was 0.0229 calorie, a discrepancy well within the limit of error when the small amounts of heat measured are taken into consideration. It is obvious, therefore, that this form of apparatus is especially well designed for studying the heat production during the mechanical motion of riding a bicycle,

for while the majority of bicyclists are capable of maintaining a fairly constant rate of speed, this apparatus is so constructed that any irregularities in speed are wholly without influence on the correctness of the final results. In order, therefore, to compute the total energy of external muscular work, it is only necessary to multiply the number of revolutions by the factor for the degree of intensity through the field. In by far the larger number of experiments the subjects rode the ergometer when the current was 1.25 amperes.

A number of subjects have ridden the bicycle ergometer inside of the respiration chamber for four periods of two hours each with this degree of resistance at a rate of about 60 to 70 revolutions per minute with no degree of discomfort. Indeed, in certain experiments the subjects have ridden for twelve to fourteen hours out of the twenty-four. On the other hand, this degree of resistance is undoubtedly somewhat more than that of riding along a level road. While most riders have preferred a resistance corresponding to 1.25 amperes through the field, the strength of current has been varied in different experiments from 0.7 to 1.25 amperes.

After a few moments' riding the disk becomes very warm, but soon the generation of heat is exactly equaled by the loss of radiation and the temperature increase ceases. Obviously, at the end of an experiment the disk is warm and loses considerable heat on cooling.

## THE RESPIRATION CALORIMETER.

The particular form of respiration calorimeter used in these experiments has been described in detail in a number of places.[a]

It will suffice here to state that the apparatus is a so-called "closed-circuit" respiration apparatus permitting the direct determination of the carbon dioxid and water vapor elimination and the oxygen consumption. The experimental periods may be made as short as two hours, as was the case in many of the experiments here reported.

As a calorimeter the apparatus is so constructed that the larger portion of the heat eliminated is absorbed by a current of cold water passing through cooling pipes or heat absorbers inside the chamber. The amount of water and the temperature through which it is warmed in its passage through the chamber are accurately measured. By special devices the double walls are rendered adiabatic, and hence the apparatus has no "cooling correction." The heat required to vaporize water inside the chamber is also taken into consideration in the final computations.

Tests of the apparatus in which known amounts of ethyl alcohol have been burned inside the chamber show that the apparatus measures with considerable accuracy the four important factors of general metabolism, namely, carbon dioxid and water vapor output, oxygen absorption, and heat elimination.

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[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 175; U. S. Dept. Agr., Yearbook 1904, p. 205; Carnegie Inst. Washington Pub. 42.

## EXPERIMENTS WITH MEN.

In the construction of the bicycle ergometer care was taken to see that the adjustment of the pedals, seat, and handle bars was such that they could be adjusted to suit almost any rider. Having demonstrated that it was comfortable to ride and substantially constructed, a number of experiments were made on men riding the ergometer inside of the respiration calorimeter chamber. Some of these experiments have already been published and indeed in considerable detail by Benedict and Milner.[a] They were primarily designed to study the relative efficiency of the fats and carbohydrates as a diet for muscular work, an amplification of earlier work with a less perfect form of ergometer.

In the study of the different diets the measurements with the ergometer formed an integral part of the experiment. But at that time the chief object was to insure that the subjects performed identically the same amount of external muscular work on all the days of the experiment. While it was desirable to know exactly the external muscular work performed for the purpose of comparing the two diets, the constancy of the amount performed each day rather than the absolute amount was of the greatest importance.

In that publication no especial discussion of the mechanical work performed or the efficiency of man as a machine was included, since it was deemed more advisable to discuss these problems along with some subsequent experiments made primarily with the view of studying the relationship between the energy of external muscular work and the total heat output.

A few experiments were made in which the subject remained inside the respiration chamber but twelve hours, i. e., the day period. The total metabolism as indicated by the carbon dioxid and water vapor output, oxygen intake, and heat elimination was studied for this period. Comparing the total heat production during this twelve-hour period with the heat production during the same period when the subject was at rest enabled a comparison to be made between the energy of external muscular work and the total heat production. It was thus possible to measure the heat required for external muscular work without including the variations in heat production during periods when work was not performed.

Finally a series of experiments was made with a professional bicyclist, who performed an excessive amount of work on the ergometer during periods of from two to four hours. The resting metabolism of this same subject was also determined and hence a satisfactory basis for comparison was available.

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[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 175.

## COMPLETE METABOLISM EXPERIMENTS.

As stated above, these experiments were a continuation of a series of experiments instituted in this laboratory to study the relative efficiency of fats and carbohydrates in diets for muscular work. They continued from one to six or more days, and included complete balances of matter and energy.

The experiments were made with three young men, students or former students in Wesleyan University, J. C. W., B. F. D., and A. L. L.

### EXPERIMENTS WITH J. C. W.

The subject was a powerful college athlete, a university track man, and possessed great endurance. During one day he rode sixteen hours with no special discomfort or after effects. He had been identified with a number of earlier experiments with the respiration calorimeter,[a] but in these earlier experiments the muscular work was unsatisfactorily measured with the form of bicycle dynamo ergometer then in use.

In these experiments the attempt was made to duplicate an earlier series in which the diet containing a large proportion of fat was compared with the diet containing a large proportion of carbohydrates, on days when substantially the same amount of external muscular work was performed.

The first experiment in which this subject used the new ergometer was metabolism experiment No. 56. For four days before this experiment began he partook of substantially the same diet that was eaten during the experiment proper. Although in this preliminary period he was not inside the respiration chamber, he nevertheless rode the bicycle ergometer for the same number of hours he proposed to ride while in the chamber. During this period the diet contained a large proportion of fat. The metabolism experiment proper continued for three days inside the respiration chamber, and the subject partook of a fat diet throughout the period. During this experiment the total output of carbon dioxid, water vapor and heat, and the intake of oxygen were carefully determined. The nitrogen balance was also found.

A second experiment made with this same subject was a duplicate of the first, save that the diet consisted for the most part of carbohydrates. There was a four-day preliminary period and also a three-day experiment in the chamber.

### HEAT PRODUCTION DURING REST.

In order to compare the resting metabolism with that during work, a four-day rest experiment with this subject had been made some time before. It is much to be regretted that a rest experiment did

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[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 136.

not immediately precede or follow the work experiments, for the one rest experiment with food (No. 35) with this subject was made over two years before. Since, however, in this study the primary object was a comparison of the fats and carbohydrates, the importance of a repetition of the rest experiment was not at that time appreciated, and the pressure of other work prevented the securing of these most important and valuable data.

The heat production obtained in several rest experiments with J. C. W. is given in the table herewith. While the resting metabolism of this subject was carefully studied in experiment No. 35, for purposes of comparison similar data for four other experiments covering five days are appended. During these experiments the subject consumed no food.

*Heat production in rest experiments with J. C. W.*

| Experiment. | Date. | 7 a. m. to 1 p. m. | 1 p. m. to 7 p. m. | Total 12 hours. | 7 p. m. to 1 a. m. | 1 a. m. to 7 a. m. | Total 12 hours. | Total 24 hours. |
|---|---|---|---|---|---|---|---|---|
| *With food.* | | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| No. 35 | Dec. 9-10, 1900 | 703 | 680 | 1,383 | 625 | 406 | 1,031 | 2,414 |
| | Dec. 10-11, 1900 | 657 | 671 | 1,328 | 595 | 464 | 1,059 | 2,387 |
| | Dec. 11-12, 1900 | 644 | 676 | 1,320 | 644 | 449 | 1,093 | 2,413 |
| | Dec. 12-13, 1900 | 663 | 665 | 1,328 | 568 | 479 | 1,047 | 2,375 |
| Average per day | | 667 | 673 | 1,340 | 608 | 449 | 1,057 | 2,397 |
| *Fasting.* | | | | | | | | |
| No. 36 | Dec. 13-14, 1900 | 627 | 611 | 1,238 | 557 | 458 | 1,015 | 2,253 |
| No. 39 | Jan. 19-20, 1901 | 551 | 517 | 1,068 | 498 | 461 | 959 | 2,027 |
| No. 42 | Mar. 6-7, 1901 | 492 | 488 | 980 | 509 | 457 | 966 | 1,946 |
| No. 51 | Apr. 1-2, 1902 | 597 | 599 | 1,196 | 681 | 485 | 1,166 | 2,362 |
| | Apr. 2-3, 1902 | 684 | 600 | 1,284 | 607 | 457 | 1,064 | 2,348 |
| All fasting experiments, average per day | | 590 | 563 | 1,153 | 570 | 464 | 1,034 | 2,187 |

In the table the results are given for the periods from 7 a. m. to 1 p. m., 1 p. m. to 7 p. m., 7 p. m. to 1 a. m., and 1 a. m. to 7 a. m. For purposes of comparison the total for each twelve-hour period is also shown. The total heat production for the twenty-four hours is given in the last column. The results show that on the whole there was a somewhat lower heat production during fasting than during periods with food. Without attempting to go into any specific discussion of the metabolism during fasting and with food, it may here be said that on all fasting days the subject undoubtedly lived under conditions of much less muscular activity than during days when food was consumed.

Since on the work days the work was all performed during the periods from 7 a. m. to 7 p. m., we have to do here, then, only with the resting metabolism for these periods. It was found that the average heat production on four days of rest, from 7 a. m. to 7 p. m., was

1,340 calories, while during inanition the heat production was 1,153 calories. In the subsequent discussion and comparison of the rest with the work periods 1,340 calories will be used as a basis.

### HEAT PRODUCTION DURING WORK.

The following table gives the total heat production of this subject for the six days of the work experiments. The results are recorded only for the period from 7 a. m. to 7 p. m., when the total work was done.

*Heat equivalent of muscular work and corrected amount of heat produced (J. C. W.), 7 a. m. to 7 p. m.*

| Experiment. | Date. | (a) Heat equivalent of muscular work. | (b) Heat produced. | (c) Heat produced over resting metabolism. | (d) Efficiency $(a \times 100) \div c$. |
|---|---|---|---|---|---|
| *Work.* | | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| No. 56 | Apr. 27-28, 1903 | 569 | [a] 3,959 | 2,619 | 21.7 |
| | Apr. 28-29, 1903 | 601 | [a] 4,139 | 2,799 | 21.5 |
| | Apr. 29-30, 1903 | 538 | [a] 3,834 | 2,494 | 21.6 |
| No. 57 | May 7-8, 1903 | 657 | 4,309 | 2,969 | 22.1 |
| | May 8-9, 1903 | 563 | 4,056 | 2,716 | 20.7 |
| | May 9-10, 1903 | 587 | 4,131 | 2,791 | 21.0 |

[a] Heat eliminated (corrected for 30 calories from bed and bedding).

The heat equivalent of the muscular work performed on the bicycle ergometer, obtained by multiplying the number of revolutions by 0.0231, is recorded in column *a*. The results obtained show that the external muscular work performed varied from day to day. It averaged about 586 calories for the six days of the two experiments.

The heat production from 7 a. m. to 7 p. m. is recorded in column *b*. For the first three days, i. e., experiment No. 56, it was impossible, owing to insufficient data, to compute the heat production. Amounts recorded show the heat elimination, corrected for the estimated amount of heat stored in the bed clothing and given off during the first period of the day, i. e., 30 calories.[a]

### MECHANICAL EFFICIENCY.

As stated above, the resting metabolism of this subject was found to be 1,340 calories during the period from 7 a. m. to 7 p. m. On the first day of experiment No. 56, therefore, this subject produced $3,959 - 1,340 = 2,619$ calories of heat in performing 569 calories of external muscular work. Thus the body was able to transform 21.7 per cent of the total energy above the resting metabolism into external muscular work. A similar computation for the remaining days of

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 136, p. 157.

the work experiments with this subject shows that with the variations in the heat of muscular work there were corresponding variations in the total energy above the resting metabolism, but the excess energy transformed into external muscular work was about 21.5 per cent for each day of the experiments.

### EXPERIMENTS WITH B. F. D.

One experiment in which the bicycle ergometer was used was made with this subject. It continued for only one day and was preceded by a three-day rest experiment. Thus the experiment may be taken as an indication of the influence of lack of training on muscular efficiency.

The data showing the heat production of this subject are given in the table below, together with corresponding data for two rest experiments, during one of which the subject fasted.

*Heat equivalent of muscular work and corrected amount of heat produced (B. F. D.), 7 a. m. to 7 p. m.*

| Experiment. | Date. | (*a*) Heat equivalent of muscular work. | (*b*) Heat produced. | (*c*) Heat produced over resting metabolism. | (*d*) Efficiency $(a \times 100) \div c$. |
|---|---|---|---|---|---|
| *Work.* | | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| No. 61 | Jan. 30-31, 1904 | 419 | [a] 3,421 | 2,177 | 19.2 |
| *Rest with food.* | | | | | |
| No. 60 | Jan. 27-28, 1904 | | 1,185 | | |
| | Jan. 28-29, 1904 | | 1,237 | | |
| | Jan. 29-30, 1904 | | 1,309 | | |
| Average | | | 1,244 | | |
| *Rest fasting.* | | | | | |
| No. 59 | Dec. 18-19, 1903 | | 1,181 | | |
| | Dec. 19-20, 1903 | | 1,134 | | |
| | Dec. 20-21, 1903 | | 1,130 | | |

[a] Heat eliminated (corrected for 30 calories from bed and bedding).

The average amount of heat produced daily during the rest experiment with food was 1,244 calories, while for the fasting experiment the corresponding amount was 1,148 calories. The latter experiment is not used for comparison with a work experiment, however, since the work was performed under conditions similar to those of the food experiment.

During the work period from 7 a. m. to 7 p. m., B. F. D. produced 3,421 calories of heat, while during the rest experiment he had produced on the average 1,244 calories. The difference, 2,177 calories, is the amount of heat produced in performing an amount of external muscular work corresponding to 419 calories of energy. The external muscular work, therefore, constituted 19.2 per cent of the energy produced in excess of that required by the subject when at rest.

## EXPERIMENTS WITH A. L. L.

The subject A. L. L., a student in Wesleyan University, entered the respiration calorimeter for a series of experiments which covered thirteen days. The first seven days were work experiments (Nos. 62, 63, and 64), of which the last was with severe muscular work. On the eighth day (experiment No. 65) the subject rested, sleeping the greater part of the time. On the ninth day (experiment No. 66) he prepared the ergometer for riding, dressed and undressed, mounted and dismounted, but did no riding. On the tenth and eleventh days (experiment No. 67) he rode the ergometer the usual number of revolutions but without any resistance. On the twelfth and thirteenth days he fasted. The full details of the fasting experiments have been reported elsewhere,[a] and have been cited in a report of experiments with J. C. W. and B. F. D. in an earlier bulletin [b] of this series.

Subsequently a four-day fasting experiment with this man was made, and the results of the resting metabolism both during the one-day experiment (experiment No. 65) with food and the six fasting days are included in the table, page 26. It is somewhat unfortunate that during experiment No. 65 the subject slept the greater part of the day to recuperate from the severe work of the day before.

On the next day, experiment No. 66, the muscular activity was unquestionably greater than during the previous day, since eight times during the day the subject prepared the ergometer for mounting and removed a portion of his clothes.

It is evident from the above statement that neither experiment No. 65 nor 66 was a "normal rest experiment." Under the circumstances it seemed best to average the heat production for the two days and assume that the result represents the heat production of this subject under conditions of "normal rest" with food, or under conditions similar to those obtained in the rest experiment with J. C. W.

In experiment No. 64 the subject rode eleven hours and the day's work was accompanied by an enormous heat production. The work was continued until after 3 o'clock in the morning, and the heat production from 7 a. m. April 22 to 4 a. m. April 23 was 6,843 calories, of which 957 were measured as external muscular work on the ergometer. The total heat production on this day is worthy of note, since from 7 a. m. April 22 until 7 a. m. April 23 the subject produced 7,143 calories of heat. The results of this series of experiments with A. L. L., together with the heat produced during fasting, is recorded in the accompanying table.

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[a] Carnegie Inst. Washington Pub. 77.

[b] U. S. Dept. Agr., Office of Experiment Stations Bul. 175.

*Heat equivalent of muscular work and corrected amount of heat produced (A. L. L.), 7 a. m. to 7 p. m.*

| Experiment. | Date. | (a) Heat equivalent of muscular work. | (b) Heat produced. | (c) Heat produced over resting metabolism. | (d) Efficiency (a×100)÷c. |
|---|---|---|---|---|---|
| *Work.* | | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| No. 62 | Apr. 16–17, 1904 | 459 | [a] 3,599 | 2,322 | 19.8 |
| | Apr. 17–18, 1904 | 458 | [a] 3,578 | 2,301 | 19.9 |
| | Apr. 18–19, 1904 | 460 | 3,602 | 2,325 | 19.8 |
| No. 63 | Apr. 19–20, 1904 | 460 | 3,657 | 2,380 | 19.3 |
| | Apr. 20–21, 1904 | 460 | 3,573 | 2,296 | 20.0 |
| | Apr. 21–22, 1904 | 458 | 3,518 | 2,241 | 20.4 |
| No. 64 | Apr. 22–23, 1904 | [b] 957 | [c] 6,843 | 4,638 | 20.6 |
| *Rest with food.* | | | | | |
| No. 65 | Apr. 23–24, 1904 | | 1,203 | | |
| No. 66 | Apr. 24–25, 1904 | | 1,351 | | |
| Average of Nos. 65 and 66 | | | 1,277 | | |
| *Coasting.* | | | | | |
| No. 67 | Apr. 25–26, 1904 | | 1,585 | | |
| | Apr. 26–27, 1904 | | [a] 1,669 | | |
| *Rest fasting.* | | | | | |
| No. 68 | Apr. 27–28, 1904 | | 1,178 | | |
| | Apr. 28–29, 1904 | | 1,183 | | |
| No. 69 | Dec. 16–17, 1904 | | 1,026 | | |
| | Dec. 17–18, 1904 | | 1,175 | | |
| | Dec. 18–19, 1904 | | 1,121 | | |
| | Dec. 19–20, 1904 | | 1,055 | | |

[a] Heat eliminated, corrected for 30 calories from bed and bedding.
[b] 8.01 a. m. to 3.01 a. m.
[c] Heat eliminated, 7 a. m. to 4 a. m.

The method of computing the proportion of energy transformed into external muscular work in experiments Nos. 62 and 63 is exactly the same as that explained on page 23. The heat equivalent of muscular work was almost the same for each day, i. e., 458 to 460 calories. The heat produced during these days varied from 3,518 to 3,657 calories, and the heat required over and above the resting metabolism (1,277 calories, the average of experiments Nos. 65 and 66) was not far from 2,300 calories. The lowest was 2,241 calories on April 21–22; the highest, 2,380 calories, on April 19–20. The average percentage of efficiency was remarkably constant, for although there was considerable difference between the first and third days of experiment No. 63, the average for the three days was very similar to the average for the three days of experiment No. 62.

Of especial interest is the percentage efficiency in the severe work experiment No. 64. On the whole this subject transformed about 19.9 per cent of the excess heat into external muscular work.

For deducting the heat production of resting metabolism for the severe work experiment, the heat production during the period from 7 a. m. to 4 a. m. of experiment No. 65 was used. This was found to be 2,205 calories. Deducting this from the total heat production of experiment No. 64, 6,843 calories, leaves 4,638 calories as the heat production necessary to produce mechanical work the heat equivalent of which is 957 calories.

WORK OF COASTING.

In this experiment the subject rode the ergometer without electrical resistance for two days, the number of revolutions on both days being the same as during experiments Nos. 62 and 63. Theoretically, at least, the values for the two days of experiment No. 67 should be the same. On the first day of the experiment, however, there were 1,585 calories of heat produced from 7 a. m. to 7 p. m., and on the second day nearly 90 calories more, i. e., 1,669 calories. Deducting the value for resting metabolism from these two values shows that in order to overcome the friction of the machine and the internal friction of the legs, the subject transformed 308 and 392 calories, respectively.

A measure of the friction of the ergometer without electrical resistance has shown that every revolution of the pedals results in the production of 0.001547 calorie. When the electrical brake is used with a current of 1.25 amperes the amount of heat produced per revolution of the ergometer is 0.0231 calorie. Assuming that the friction remains constant, about 6.5 per cent of the total heat resulting from one revolution of the pedals is due to friction. Accordingly, if sufficient external muscular work is done to produce 460 calories of heat, 29.9 calories will be produced as the result of friction. Under the above conditions, therefore, a rider whose mechanical efficiency is 20 per cent will expend 149.5 calories to overcome the friction of the ergometer. Deducting this amount from the total heat output above the resting value gives 158.5 calories and 242.5 calories as the energy required to overcome the friction of the muscles. Owing to unavoidable circumstances, in these experiments the agreement between the results for the two days is very unsatisfactory and the computations are probably open to considerable error.

It may reasonably be contended that another method of measuring the mechanical efficiency of the man could be more correctly obtained by deducting the total heat production during the coasting experiment from that during work and using the difference to compute the total heat of external muscular work. Thus if we take the average of the two days of experiment No. 67, the heat production for the period from 7 a. m. to 7 p. m. was 1,627 calories, but during this period there was produced by the friction of the ergometer 29.9 calories. The average heat equivalent of muscular work of the six days of experiments Nos. 62 and 63 was 459 calories, the total heat produced 3,588 calories, and deducting from the total produced 1,627, which is the heat produced during the coasting period, we have 1,961 calories as the heat above the rest-coasting metabolism. It is necessary, however, also to deduct 29.9 calories from the heat equivalent of muscular work, and thus it is seen that the 1,961 calories eliminated above the energy of coasting metabolism resulted in the production of 429.1 calories of external muscular work. Of this 1,961 calories 21.9 per cent was converted into external muscular work.

## TWELVE-HOUR EXPERIMENTS WITH MEN.

### EXPERIMENTS WITH B. F. D. AND E. F. S.

The next series of experiments with the bicycle ergometer was conducted with B. F. D., who had been the subject of an earlier experiment. In this series of experiments the subject entered the respiration chamber early in the morning and remained quiet until 7 a. m. During the first day he rode the ergometer a total of 25,959 revolutions. The subject worked in four two-hour periods, although the heat measurements were made in three-hour periods. No attempt was made to have the work uniform throughout all periods. On the second day, March 2, the experiment did not continue after 1 p. m. On the third day the resting metabolism of the subject was determined for purposes of comparison. The average number of revolutions per minute was 60 on the first day and 56 on the second, there being a little less than half as much work done on the second day.

With the subject E. F. S., the number of revolutions on the one day of the experiment, i. e., March 5, was somewhat greater than on the first day with B. F. D. The rate of revolution varied from 56 to 63 per minute. In all the short experiments with these two men the current through the magnet had a strength of 1.25 amperes. The results are collected for purposes of comparison in the following table:

*Heat produced in experiments with B. F. D. and E. F. S.*

| Date. | Period. | (a) Heat produced. | (b) Number of revolutions. | (c) Number of revolutions per minute. | (d) Current. | (e) Heat equivalent of muscular work. | (f) Heat produced over resting metabolism. | (g) Efficiency $(e\times100)\div f$. |
|---|---|---|---|---|---|---|---|---|
| B. F. D. | | | | | | | | |
| *Work.* | | *Calories.* | | | *Amperes.* | *Calories.* | *Calories.* | *Per cent.* |
| March 1, 1904. | 7 a. m. to 7 p. m. | 4,085.44 | 25,959 | 60 | 1.250 | 599.65 | 2,746.80 | 21.83 |
| March 2, 1904. | 7 a. m. to 1 p. m. | 1,962.80 | 12,645 | 56 | 1.250 | 292.10 | 1,279.97 | 22.82 |
| *Rest with food.* | | | | | | | | |
| March 3, 1904. | 7 a. m. to 7 p. m. | 1,338.64 | | | | | | |
| | 7 a. m. to 1 p. m. | 682.83 | | | | | | |
| E. F. S. | | | | | | | | |
| *Work.* | | | | | | | | |
| March 5, 1904. | 7 a. m. to 7 p. m. | 4,782.02 | 26,495 | 61 | 1.250 | 612.03 | [a]3,382.02 | 18.10 |

[a] Resting metabolism assumed as 1,400 calories. See page 29.

For obtaining the resting metabolism with B. F. D. the values found on March 3 were used instead of those in the earlier experiments. For the six hours on March 2 the corresponding six hours on March 3 were taken as indicating the resting metabolism.

No resting experiment with E. F. S. was made, as the subject left Middletown shortly after the conclusion of this experiment. His body weight was 80 kilograms, and from a large amount of data

obtained with other subjects, it is highly probable that his resting metabolism would be not far from 1,400 calories for the period from 7 a. m. to 7 p. m. Accordingly in the computations given in the table this resting metabolism has been assumed.

## EXPERIMENTS WITH A PROFESSIONAL BICYCLIST.

Since it was believed that experiments with a subject who had long been trained for bicycle riding would give most interesting results regarding the efficiency of man as a machine, and that with such a subject the most satisfactory results with this form of ergometer could be obtained, arrangements were made with a professional bicyclist to come to Middletown and spend a number of days riding the ergometer inside the respiration chamber. He was so much interested in the outcome of the experiments that he volunteered to act as subject and in every way seconded our efforts to secure accurate and complete experiments, and his intelligent appreciation of the scientific nature of the work contributed in large measure to the success of the experiments. The experiments were made from October 21 to 24, 1904, and from January 23 to 26, 1905.

The subject N. B. was 35 years of age, weighed 66 kilograms, and was 172 centimeters in height. Since early life he had been engaged in bicycle riding and had established himself as one of the foremost professional bicycle riders in America. His experience had included not only short races but also the more tiring and strain-producing six-day bicycle races. In excellent condition, practically a total abstainer from alcoholic beverages, he was an ideal subject for the experiments.

### GENERAL PLAN OF THE EXPERIMENTS AND THE RESULTS OBTAINED.

The experiments with N. B. were all short experiments and he did not remain in the calorimeter over night. In general the subject entered the respiration chamber about one hour before the actual experimental period began. In the work experiments, as soon as he entered the calorimeter, he began to ride the ergometer, and after the calorimeter had reached temperature equilibrium the experiment proper was begun. Thus the temperature conditions inside the chamber were approximately the same at the beginning and at the end of each experiment. The periods usually lasted from one and one-half to three hours, and in most experiments duplicate periods could be obtained and the accuracy of the measurements was thus checked to a certain extent.

The first experiment, which was made October 21, 1904, began at at 2.39.30 in the afternoon, and continued for approximately two hours. During this period the subject rode the ergometer with a current of 1.25 amperes, and the total metabolism as measured by the carbon dioxid output, oxygen intake, and heat elimination was

obtained. On the following morning a three-hour rest experiment was made to secure the resting metabolism of the subject. At the conclusion of this rest experiment the subject did not leave the respiration chamber, but after a rest of one hour, during which he ate his lunch, began to ride the ergometer, and a work experiment was begun at 2 p. m. which lasted three hours. The strength of current and the number of revolutions per minute were substantially the same as in the experiment of the previous day. On October 24 a three-hour experiment was made in which the subject rode the ergometer without resistance. This experiment was therefore a so-called "coasting" experiment.

Three months later a more extended series of experiments was made with this subject. On January 23, 1905, a two-hour rest experiment was followed by two one and one-half hour periods of work, during which the current of 1.25 amperes was passed through the magnet of the ergometer.

Later the degree of resistance applied to the ergometer was adjusted to correspond as nearly as Mr. Butler could estimate with the amount of work per hour done during a six-day race, since experience showed that the current of 1.25 amperes was somewhat too strong, and consequently three experiments were made with the strength of the current 0.9, 0.8, and 0.7 ampere, respectively. On January 24 the subject rode for two two-hour periods against a resistance of 0.9 ampere, and on the following day he rode for two two-hour periods with less resistance (0.8 ampere).

On January 26 two experiments were made. During the first the subject "coasted" and during the second he rode the ergometer against a resistance of 0.7 ampere. The actual records of the experiments are shown in the following table:

*Heat produced, carbon dioxid eliminated, oxygen absorbed, and water vaporized in experiments with N. B.*

| Date. | Period. | Current. | Heat produced. | Heat equivalent of work done. | Number of revolutions. | Number of revolutions per minute. | Carbon dioxid eliminated. | Oxygen absorbed. | Water vaporized. |
|---|---|---|---|---|---|---|---|---|---|
| 1904. | | *Amperes.* | *Calories.* | *Calories.* | | | *Grams.* | *Grams.* | *Grams.* |
| Oct. 21 | 2.40 p. m. to 4.25 p. m. | 1.250 | 1,101.31 | 184.06 | 7,968 | 76 | 379.07 | ...... | 149.73 |
| 22 | 9.20 a. m. to 12.24 p. m. | Rest. | 290.80 | .......... | ...... | ...... | 87.83 | ...... | 145.86 |
| 22 | 2 p. m. to 4.58 p. m. | 1.250 | 1,827.93 | 343.54 | 14,872 | 84 | 617.74 | ...... | 226.78 |
| 24 | 9.10 a. m. to 12.10 p. m. | Coasting. | 547.35 | .......... | 14,874 | 83 | 186.45 | ...... | 167.77 |
| 1905. | | | | | | | | | |
| Jan. 23 | 10.59 a. m. to 12.59 p. m. | Rest. | 179.30 | .......... | ...... | ...... | 58.81 | 45.53 | 63.85 |
| 23 | 2.16 p. m. to 3.46 p. m. | 1.250 | 914.35 | 171.06 | 7,405 | 82 | 347.44 | 275.79 | 103.61 |
| 23 | 3.46 p. m. to 5.17 p. m. | 1.250 | 952.61 | 174.64 | 7,560 | 83 | 320.21 | 265.97 | 102.65 |
| 24 | 9.47 a. m. to 11.45 a. m. | .900 | 934.11 | 157.49 | 9,051 | 77 | 302.86 | 281.77 | 109.30 |
| 24 | 11.45 a. m. to 1.47 p. m. | .900 | 948.77 | 157.47 | 9,050 | 74 | 323.46 | 284.16 | 147.85 |
| 25 | 11.03 a. m. to 1.02 p. m. | .800 | 779.90 | 127.56 | 8,177 | 69 | 248.20 | 227.95 | 136.92 |
| 25 | 1.02 p. m. to 3.02 p. m. | .800 | 819.23 | 133.27 | 8,543 | 71 | 279.52 | 251.41 | 101.74 |
| 26 | 10.36 a. m. to 12.36 p. m. | Coasting. | 363.19 | .......... | 9,919 | 83 | 127.00 | 114.85 | 101.19 |
| 26 | 12.36 p. m. to 2.36 p. m. | .700 | 764.72 | 119.82 | 9,361 | 78 | 276.38 | 222.14 | 110.72 |

Since the length of the experiments varied somewhat, the results have all been computed to amounts per hour, and these values are given in the table herewith:

*Results of experiments with N. B. calculated to one-hour basis.*

| Date. | Period. | (*a*) Current. | (*b*) Water vaporized. | (*c*) Carbon dioxid eliminated. | (*d*) Oxygen absorbed. | (*e*) Heat produced. | (*f*) Heat equivalent of work done. | (*g*) Heat above resting metabolism. | (*h*) Efficiency $(f \times 100) \div g$. |
|---|---|---|---|---|---|---|---|---|---|
| 1904. | | *Amperes.* | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| Oct. 21 | First... | 1.25 | 85.02 | 215 24 | .......... | 625.35 | 104.51 | 531.18 | 19.68 |
| 22 | First... | Rest. | 47.43 | 28.56 | .......... | 94.17 | .......... | .......... | .......... |
| 22 | Second. | 1.25 | 76.39 | 208.07 | .......... | 616.16 | 115.71 | 521.99 | 22.17 |
| 24 | First... | Coasting. | 55.92 | 62.15 | .......... | 182.45 | .......... | .......... | .......... |
| 1905. | | | | | | | | | |
| Jan. 23 | First... | Rest. | 31.93 | 29.41 | 22.77 | 89.65 | .......... | .......... | .......... |
| 23 | Second. | 1 25 | 68.89 | 231 03 | 183 38 | 607 99 | 113.75 | 518.34 | 21.95 |
| 23 | Third.. | 1.25 | 67 43 | 210 36 | 174.[illegible]2 | 625.80 | 114.73 | 536.15 | 21.40 |
| 24 | First... | .90 | 55.38 | 153 45 | 142.77 | 473 30 | 79 80 | 383.65 | 20.80 |
| 24 | Second. | .90 | 72.96 | 159 62 | 140 23 | 468.21 | 77 71 | 378.56 | 20.53 |
| 25 | First... | .80 | 68 84 | 124.79 | 114.61 | 392 13 | 64.14 | 302.48 | 21.20 |
| 25 | Second. | .80 | 50.87 | 139 76 | 125.71 | 409 62 | 66.64 | 319.97 | 20.83 |
| 26 | First... | Coasting. | 50.60 | 63.50 | 57 43 | 181.60 | .......... | .......... | .......... |
| 26 | Second. | .70 | 55.36 | 138.19 | 111.07 | 382.36 | 59.91 | 292.71 | 20.47 |

In the January series of experiments it was possible to secure an approximate measurement of the amount of oxygen absorbed, and in the table are included the amount of carbon dioxid eliminated, water vaporized, oxygen absorbed, and the heat production.

## INFLUENCE OF MUSCULAR WORK ON GENERAL METABOLISM.

The values recorded in the table above showing the amount of water vaporized, carbon dioxid eliminated, and oxygen consumed indicate the marked influence of muscular activity on the general metabolism.

Of especial importance in this discussion are the heat production and the heat equivalent of work done. As a result of the intense muscular work performed by this subject the heat production reached the astounding maximum of 626 calories per hour. On the four different periods when the hardest work was done the heat production per hour was 608, 616, 625, and 626 calories, respectively. During these severe work periods the amount of transformation of external muscular work reached 116 calories. The resting metabolism was independently determined for both series of experiments, and in computing the excess of heat produced above the resting metabolism, the values found for rest during each series were used. The heat produced above the resting metabolism is recorded in the table. The efficiency varied from 19.68 to 22.17, averaging 21 per cent.

## WATER VAPORIZED.

The primary object of the measurements of water vaporized in these experiments was to obtain the heat production, since a part of the heat production is expended in vaporizing water from the lungs and

skin (0.592 calorie per gram of water). As a matter of fact, during the riding periods his clothing was saturated with perspiration and he was literally reeking with perspiration when he left the chamber. The sensible perspiration, however, does not modify in any way the heat measurement. In the form of calorimeter used in these experiments a current of cold water is passed through a heat-absorbing system inside the chamber. The temperature of the water during these work experiments is nearly 0° C., and consequently there is a condensation of moisture from the air on these absorbers. This amounted, therefore, to a distillation of water from the body of the subject upon the absorbers, but obviously only the water that was vaporized and not again condensed affects the heat measurements, and accordingly the values for water vaporized have no significance whatever as indexes of the amount of sensible and insensible perspiration, except in the rest experiments. The values recorded in the table under the head of water vaporized are very misleading. There was no sensible perspiration during either of the rest experiments.

While from the amount of water condensed on the absorbers and the increase in weight of the underclothing it is possible in most experiments with muscular work to obtain data regarding the total sensible and insensible perspiration, in these series of experiments provision could not be made for a satisfactory study of these excretions, and accordingly we were obliged to forego a study of the perspiration.

## CARBON DIOXID EXCRETED.

Muscular work resulting from the transformation of body material is accompanied by an increase in the excretion of carbon dioxid and absorption of oxygen. Of these two factors, the carbon dioxid excretion has been more commonly studied. In all the experiments with N. B. the carbon dioxid was accurately measured. The results computed to the excretion per hour have been previously given (table, p. 31). It may be seen from the data that during the October experiments this subject excreted 28.56 grams of carbon dioxid per hour when at rest. During the corresponding January experiment he excreted 29.41 grams per hour, an agreement that is most satisfactory considering the length of time between the two experiments.

The most marked influence of excessive muscular work on the carbon dioxid excretion is seen from the amounts eliminated on the days of severe muscular work. These amounts frequently exceeded 200 grams per hour. Indeed, during the first period, January 23, the amount of carbon dioxid eliminated was 231.03 grams. This is nearly eight times the elimination during rest. A moderate degree of muscular activity, such as that produced by riding the ergometer without resistance, i. e., during coasting, approximately doubled the

carbon dioxid output, and here, too, it is of interest to note that the values obtained during coasting in October and January were nearly the same, i. e., 62.15 and 63.50 grams, respectively.

The relation between the carbon dioxid output and the heat production are very evident if the values shown in columns *c* and *e* (table, p. 31) are compared. The large heat production is accompanied by a large carbon dioxid elimination. An inspection of the figures, however, shows that the relation between the carbon dioxid and the heat production is not constant. Thus, during the first work period of the experiment on January 23, when the maximum amount of carbon dioxid was eliminated, i. e., 231.03 grams, there were 607.99 calories of heat produced, while during the second work period of the same day, when a maximum heat production was obtained, namely, 626 calories, the carbon dioxid production was actually 20 grams less. This serves to show the difficulties of computing accurately the heat production from the carbon dioxid output. While, therefore, the carbon dioxid output is markedly and immediately influenced by excessive muscular exertion, it is not safe to assume that there is constant relation between the carbon dioxid output and the heat production.

## OXYGEN ABSORBED.

Although during the October experiments the measurements were not satisfactory, in the second series of experiments with N. B. it was possible to measure the oxygen absorption with reasonable accuracy. The same influence on the quantities of oxygen absorbed that was noted on the carbon dioxid elimination may be seen here. The excessive muscular work increases markedly the oxygen absorption. But an inspection of the figures shows that, at least as far as these results go, there is not an absolute uniformity between the ratios of the oxygen absorbed and the heat produced. During rest this subject absorbed 22.77 grams of oxygen per hour. During muscular work the oxygen absorption increased in one experiment to 183.38 grams per hour.

## CONDITIONS INSIDE THE RESPIRATION CHAMBER.

Although the subjects perspired freely during the work periods, and especially in the case of N. B., the clothing was drenched with perspiration, yet the nature of the special form of calorimeter used prevented any excessive accumulation of water vapor inside the respiration chamber. The water entering the heat-absorbing pipes was very cold, and hence the moisture condensed out of the air on these pipes and collected in troughs suspended under the absorbers. Thus, while there was an enormous evaporation of water from the

lungs and skin of the subject, so rapidly was it condensed on the heat absorbers that the humidity of the air inside the chamber rarely rose above 70 per cent.

There was entire absence of air currents, at least such as were perceptible to the man. The total quantity of air entering the chamber amounted to but 75 liters per minute, approximately 3 cubic feet, and this entered in such a manner as to be directed toward the floor of the calorimeter. By means of the heat-absorbing appliances the temperature of the calorimeter was kept invariably at 19° to 20° C., and inasmuch as the humidity did not rise to any excessive point the subjects underwent no discomfort as a result of defective thermolysis. There was no air current inducing rapid evaporation such as is common when riding a bicycle in the open air, and moreover there was no wind resistance.

## GENERAL DISCUSSION OF RESULTS.

### PERSONAL IMPRESSIONS OF THE SUBJECTS OF THE EXPERIMENTS.

So far as can be judged from the personal impressions of the subjects, no especial discomfort was noticed in any of the experiments. All complained of the monotony, and N. B. stated that he had never worked as hard in his life, not even in the most severe race, as he did during the periods when the ergometer was magnetized with a current of 1.25 amperes. The psychical stimulus of the crowd of spectators at a race was wanting, and the riding became very tedious.

When the ergometer was magnetized with a current of 0.9 ampere the subject felt that he was doing about the work that would be called for in the continuous riding of a six-day race. Although a personal impression, this observation is of much value in subsequent discussion.

### SUMMARY OF RESULTS OF MUSCULAR WORK EXPERIMENTS.

The special purpose of this study being to observe the relationship between the total heat production and the heat equivalent of external muscular work, the results of all the experiments have been calculated to amounts per hour and the abstract of the results recorded in the following table.

*Summary of results of muscular work experiments.*

[Amounts per hour.]

| Subject. | (a) Current through magnet. | (b) Revolutions per minute. | (c) Resting. | (d) Total heat produced. | (e) Heat equivalent of muscular work. | Mechanical efficiency. (f) $\frac{e \times 100}{d}$ | (g) $\frac{e \times 100}{d-c}$ |
|---|---|---|---|---|---|---|---|
| | *Amperes.* | | *Calories.* | *Calories.* | *Calories.* | *Per cent.* | *Per cent.* |
| J. C. W., average of six days | 1.25 | ........ | [a] 112 | 339 | 49 | 14.5 | 21.6 |
| B. F. D., average of three experiments | 1.25 | ........ | [a] 106 | 318 | 45 | 14.2 | 21.2 |
| A. L. L., average of six days | 1.25 | 51 | [b] 106 | 299 | 38 | 12.7 | 19.7 |
| A. L. L., extra severe work one day | 1.25 | ........ | 105 | 326 | 46 | 14.1 | 20.8 |
| A. L. L., coasting, average of two days | ........ | 51 | ........ | 135 | ........ | ........ | ........ |
| E. F. S., one day | 1.25 | ........ | [c] 117 | 399 | 51 | 12.8 | [d] 18.1 |
| N. B., average of four experiments | 1.25 | 81 | [e] 92 | 619 | 112 | 18.1 | 21.3 |
| N. B., average of two experiments | .90 | 76 | | 471 | 79 | 16.8 | 20.8 |
| N. B., average of two experiments | .80 | 70 | | 401 | 65 | 16.2 | 21.0 |
| N. B., one experiment | .70 | 78 | | 382 | 60 | 15.7 | 20.7 |
| N. B., coasting, average of two experiments | ........ | 83 | ........ | 182 | ........ | ........ | ........ |

[a] Average of four days.
[b] Average of two days.
[c] Average based on resting output (1,400 calories) assumed. See page 29.
[d] Not included in average.
[e] Average of two experiments.

In the majority of the experiments the strength of the current used for magnetizing the fields was 1.25 amperes, although three experiments with N. B. were made with weaker currents. The resting metabolism was taken as the average of such experiments as were available for the different individuals, save in the case of E. F. S., where a resting metabolism estimated from a large number of experiments with individuals of a similar weight was taken. In averaging the experiments with B. F. D. the total heat produced during rest (with food) was taken as the average of three experiments, two of twelve hours each and one of six hours.

The resting metabolism for the severe work experiment was taken as the heat production per hour for the rest period corresponding to the work period. The heat production during coasting was also recorded for this subject. With the subject A. L. L. the average results of the two ordinary work experiments are given, as is also the result of the severe work experiment.

In all the experiments except those with N. B. it must be borne in mind that the subjects were not continuously at work during the experimental period. Thus in the experiments with J. C. W. each experimental period covered twelve hours, while the actual work occupied only eight of these twelve hours. Similarly, the work periods with A. L. L. and B. F. D. were only about eight out of the twelve hours. Even in the extra severe work of A. L. L. the actual working time was much less than the experimental periods. However, since in the computation of the results the resting metabolism

is deducted from the total heat produced, the fact that the work was not continuous throughout the experimental period does not affect the results.

On the other hand, in all the experiments with N. B. the work period and the period of experiment were coincident. For that reason the total heat production per hour was very much larger with this subject than with any other.

## MECHANICAL EFFICIENCY OF THE HUMAN BODY.

### METHODS OF CALCULATION AND RESULTS.

Two methods of computing the mechanical efficiency may be used. By the first method the heat equivalent of muscular work is compared to the total heat production. By the second method the heat equivalent of muscular work is compared to the total heat production less the resting metabolism. This latter method has been more commonly used, but the results by both methods of computation are given in the table. Since the experimental periods were not always coincident with the working periods, the results are more comparable when considered on the latter basis, and, consequently, the heat equivalent of external muscular work is compared with the total heat production less the resting heat output. The results show a striking uniformity in the mechanical efficiency of all of these men, averaging not far from 20.9 per cent. The lowest was that observed in the case of E. F. S., 18.1 per cent, but, as has been shown above, the resting value for this subject was estimated and not measured.

Perhaps the most surprising feature of these results is that the professional bicycler, N. B., showed practically no higher efficiency than the other subjects. While J. C.W. was a trained bicycler, A. L. L. was entirely unfamiliar with bicycle riding before he began these experiments, and both B. F. D. and E. F. S. had had but little experience in riding the bicycle. That the trained muscles of the professional bicycler should not have shown a greater efficiency than did the muscles of the younger and less experienced men is indeed surprising. It is, however, to be borne in mind that the experiments are not strictly comparable, and while our experience would indicate that substantially the same efficiency would be found with the other men in experiments on the plan of those made with N. B., nevertheless such experiments should be made before a final conclusion is drawn regarding the effect of training.

It should be added that the experiments in which the resting value with N. B. was obtained were conducted on a somewhat different plan than those with the other subjects, in that the subject was very quiet and did not have the freedom of movement allowed the other men.

The computation of the mechanical efficiency of a man is beset with certain difficulties not experienced with the ordinary form of heat engines. Thus the body requires a certain amount of energy to maintain it in the resting condition. This is not far from 2,300 calories per day, although the amount differs with the individual.

The work performed by the body may be said to consist of two kinds, internal and external. Of these two, it is possible for us in these experiments to measure only the external work expended in riding. From the data given in the statistics of the experiments it is possible to find what proportion of the energy produced above the resting metabolism can be converted into external muscular work, and on this basis the proportion is very high. On the contrary, it may be stated that the percentage should be based upon the total heat production for the day, and thus involve the heat production during rest. Calculated on this basis, the efficiency is obviously very much lower. The degree to which the calculation of the percentage efficiency would be affected by including the resting heat production depends in large part upon the total heat production during the work experiments. If the heat production is very large, the including of the heat of resting metabolism does not influence the final result to anything like the extent that it would if the total heat production during work were small. This is especially noticeable in the experiment with A. L. L., in which he worked for a good part of the day. The percentage efficiency computed on the basis of heat production above resting metabolism is 20.8 per cent, while the percentage of the total energy transformed into external muscular work is 14.1 per cent. In the table on page 35, column *f*, the results for all the experiments are included, showing the mechanical efficiency of the man based upon the total heat production of the day.

While it is impossible to measure the thermal equivalent of the internal muscular work, it is also impossible to measure the thermal equivalent of the external muscular exertion involved in preparing the ergometer to ride, dressing and undressing, mounting and dismounting, but it would be of interest to compute the efficiency of the subjects deducting not only the heat production during rest but also the heat production incidental to the preparation of the ergometer, etc.

The same difficulties that are encountered in attempting to measure the heat equivalent of the extraneous muscular exertion incidental to preparation of the wheel are likewise encountered in determining accurately the thermal equivalent of the internal friction of the muscles of the leg when riding the bicycle ergometer. The experiments in which the subject rode or coasted with free leg motion were made with the specific purpose of permitting the deduction from the total heat output of the heat required to rotate the ergom-

eter without resistance other than the slight amount due to mechanical friction. A series of computations, therefore, is of interest to show the actual heat production necessary to produce the heat of external muscular work recorded in these experiments over and above that required to rotate the ergometer without resistance. These data also furnish the means for computing mechanical efficiency on another basis.

### "COASTING" ON A BICYCLE.

In the process of riding the ergometer without resistance, which has here been called "coasting," two factors come into play. First, the energy required to overcome the friction of the machine, and second, the internal friction of the muscles. From the construction of the bicycle it can readily be seen that the weight of the two legs on the pedals is practically counterbalanced, so that one leg in descending counterbalances the other leg when raised and thus no mechanical work is called for. From a calibration of the ergometer in which the machine was placed inside the respiration chamber and rotated without electrical resistance, it was found that each revolution of the pedals produced sufficient friction to correspond to 0.001547 calorie of heat. Therefore in coasting the different subjects must have performed this amount of work for each revolution. With two subjects the amount of heat eliminated during a coasting period was determined. A. L. L. coasted eight out of twelve hours on two days, and the heat production per hour was found to be 135 calories. N. B. coasted for shorter periods, but two experiments showed an average of 182 calories per hour. That these two values do not compare is due to the fact that during the hours that N. B. was coasting he worked continuously, while with A. L. L. the figure represents the value for eight hours actual coasting, divided by twelve, the number of hours in the experimental period. As a matter of fact, while coasting, N. B. rode at a faster rate than did A. L. L.

### CALCULATION OF MECHANICAL EFFICIENCY BASED ON COASTING ON A BICYCLE.

In computing the efficiency of the body as a machine, it may be of value to calculate this efficiency not only by deducting the resting heat output from the total heat production during a work period, but also by deducting the heat output during coasting. The difference between the total output during severe work and that during the coasting period corresponds, then, to the energy required to transform the external muscular work into heat. In three experiments with N. B. with a current of 1.25 amperes the average heat

production per hour was 617 calories; the heat equivalent of muscular work was 115 calories; the coasting value was 182 calories. Since in coasting, however, the friction of the ergometer corresponds to 8 calories per hour, it is necessary not only to deduct from the total heat output the coasting heat output, but also to deduct from the heat equivalent of muscular work the heat equivalent of the friction of the machine during coasting, i. e., 8 calories. The results for the different series of experiments with N. B. are recorded in the table which follows:

*Mechanical efficiency based on coasting.*

[Amounts per hour.]

| Subject. | (a) Current. | (b) Revolutions per minute. | (c) Heat produced during work. | (d) Heat produced during coasting. | (e) Estimated heat required for work (c—d). | (f) Heat equivalent of work (less friction). | (g) Efficiency. $\frac{f\times 100}{e}$ |
|---|---|---|---|---|---|---|---|
| | *Amperes.* | | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| N. B | 1.25 | 83 | [a] 617 | 182 | 435 | [a] 107 | 24.6 |
| N. B | .90 | 76 | 471 | 167 | 304 | 72 | 23.7 |
| N. B | .80 | 70 | 401 | 153 | 248 | 58 | 23.4 |
| N. B | .70 | 78 | 382 | 171 | 211 | 52 | 24.6 |
| A. L. L | 1.25 | .......... | 299 | 135 | 164 | 35.5 | 21.6 |

[a] Average of three experiments. Does not include experiment of October 21, 1904.

In column *e* is given the total heat production less the heat production during coasting, and in column *f* the heat equivalent of muscular work due to the electric brake, i. e., the heat equivalent of muscular work less the heat equivalent of the friction during coasting. Assuming a rate of eighty-three revolutions per minute, the heat equivalent of the friction may be readily computed as follows: $83\times 60=4{,}980$ revolutions per hour. This multiplied by the factor 0.001547 gives a total heat production per hour at the rate of eighty-three revolutions per minute of about 8 calories, and consequently the work to overcome the electrical resistance of 1.25 amperes was 107 calories. We may then say that of the 435 calories required to overcome the electrical brake effect of the ergometer 107 were transformed into the heat equivalent of external muscular work. The efficiency computed on this basis is 24.6 per cent.

Calculations at other intensities of magnetization of the fields of the magnet gave similar results. Unfortunately, in the other series of experiments the rate per minute varied somewhat, and in computing the values in column *d* it was assumed that the coasting rate at the same number of revolutions per minute would be proportional to the rates of revolution. Thus at 0.9 ampere the heat production during coasting at the rate of 76 revolutions per minute was computed as follows: $76:83=x:182$. $x=167$. The other computations are identical with those for the experiments with 1.25 amperes.

Computed on this basis, the percentage efficiency is considerably higher than on either of the other bases, and there is not the uniformity in the efficiency percentage which is noted in the other calculations. Two factors enter into this method of computation which are not as perfectly established as they should be. First, the energy of friction per revolution of the pedals without electrical resistance has been determined in only one experiment, and obviously the value to be deducted from the heat equivalent of muscular work in the different experiments, especially with N. B., may contain a considerable error. Again, it is assumed that the heat output during coasting would be proportional to the number of revolutions per minute.

The experiment with A. L. L. permits of a similar comparison of the mechanical efficiency obtained by deducting the heat output during coasting from the total heat output. The values are given in the lower part of the table. In this experiment the rates per minute were the same during both the work and the coasting period. There is, however, a marked difference in that the riding was done irregularly throughout the day and occupied but eight of the twelve experimental hours; the number of revolutions made during coasting was likewise distributed throughout the twelve hours of the experiment, but, on the other hand, they were the same in number as those during the work experiment. While there is distinct objection to comparing the experiments with A. L. L. with those made with N. B., the results show that the percentage efficiency of A. L. L. computed on this basis is noticeably less than that with N. B. In so far, then, as the results of these experiments show, the professional bicycler N. B. had a somewhat higher efficiency than the other subject when this efficiency is computed by deducting from the total heat output during work the output during coasting.

## INTERNAL FRICTION OF LEG.

In the operation of coasting the subject has to overcome the friction of the machine as well as the internal friction of the leg, and from the two experiments with A. L. L. and N. B. an approximate indication of the work of internal friction may be had. A. L. L., riding the ergometer approximately eight hours per day had a rate of speed of 51 revolutions per minute and produced on two days 1,585 and 1,669 calories of heat, respectively. The resting metabolism was taken as 1,277 calories, and hence the excess over resting was on the first day 308 and on the second 392 calories. From the total number of revolutions and the heat of friction per revolution it is calculated that the work of friction of the machine amounted to 29.9 calories. From the experiments made with a number of men and here reported, it is seen that the mechanical efficiency of the

man is not far from 20 per cent, and hence the actual heat output required to rotate the machine and overcome the work of friction would be the heat equivalent of the friction × 5, or in these two experiments 149.5 calories. Deducting this value from the difference between the coasting and the resting metabolism gives the value for the work of internal friction of the legs. For the two days it is 158.5 and 242.5 calories, respectively. The agreement is far from satisfactory. On the first day, therefore, of the total excess heat above the resting metabolism, approximately one-half was required to overcome the friction of the machine and a little over one-half to overcome the work of internal friction. On the second day 60 per cent of the excess heat was required for the work of internal friction. In one experiment with N. B. the results are as follows: The average rate per minute when coasting was 83, the resting metabolism 92 calories per hour, coasting 182 calories, and the excess over coasting 90 calories. The computation of the work of friction shows it to be 8 calories per hour, and the energy required to produce this work was consequently 40 calories. This deducted from the excess of coasting over resting yields 50 calories per hour as the work of internal friction. These results with N. B. are comparable with those of A. L. L. only in so far as the proportion of the excess heat is due to work of internal friction. On the two experiments with A. L. L. the work of internal friction was 51.5 and 61.9 per cent of the total excess over resting metabolism, respectively, while with N. B. the work of internal friction was 55.6 per cent of the excess over the resting metabolism.

*Heat due to internal friction of legs in coasting experiments with A. L. L. and N. B.*

| Subject. | Day. | (*a*) Revolutions per minute. | Heat production. | | | Friction of machine. | | Heat due to friction of legs. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | (*b*) Rest. | (*c*) Coasting. | (*d*) Excess coasting over resting (*c*—*b*). | (*e*) Heat equivalent of friction. | (*f*) Estimated heat output (*e*×5). | (*g*) Amount (*d*—*f*). | (*h*) Proportion of excess during coasting (*g*×100) ÷*d*. |
| | | | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Per cent.* |
| A. L. L. | First | 51 | 1,277 | 1,585 | 308 | 29.9 | 149.5 | 158.5 | 51.5 |
| A. L. L. | Second | 51 | 1,277 | 1,669 | 392 | 29.9 | 149.5 | 242.5 | 61.9 |
| N. B.[a] | Average of 2 days. | 83 | 92 | 182 | 90 | 8.0 | 40.0 | 50.0 | 55.6 |

[a] Results per hour.

## MECHANICAL EFFICIENCY AS AFFECTED BY VARYING DEGREES OF INTENSITY OF WORK.

It has been commonly believed that the human body in common with the ordinary steam engine varies its efficiency with the load. For each engine there is a load at which the maximum efficiency is

obtained. In certain of these experiments the data regarding the heat production and heat of external muscular work are sufficiently complete to furnish evidence regarding the effect of load on the efficiency of the human machine.

With increasing load there was increased total heat production and increased heat of external muscular work, and it remains, therefore, to consider what effect on the efficiency was produced by the variations in load.

While the use of the resting metabolism as a base line for the computation of the efficiency is open to the objections stated above, for the calculation of the effect of increased load the data are sufficient and much less open to criticism. Thus in order to increase the heat of external muscular work by 5 calories per hour the current through the electro-magnet was increased to 0.7 to 0.8 ampere and the total heat production per hour rose from 382 calories with 0.7 ampere to 401 calories with 0.8 ampere. Coincidently, the heat equivalent of external muscular work increased 60 to 65 calories per hour. Thus an increase of 5 calories in the external muscular work was accompanied by or necessitated an increased heat production amounting to 19 calories. A simple calculation shows that of the increased heat production 26 per cent was converted into heat of external muscular work.

Similar computations for the various increases in load are given in the following table, the data being obtained from the last part of the table on page 35:

*Effect of increasing external work on body efficiency.*

| (a) Increase in magnetization from— | (b) Increase of total heat. | (c) Increase of heat of external work. | Efficiency. $\frac{(c \times 100)}{b}$ |
|---|---|---|---|
| *Amperes.* | *Calories.* | *Calories.* | *Per cent.* |
| 0.7 to 0.8 | 19 | 5 | 26.0 |
| .7 to .9 | 89 | 19 | 21.3 |
| .7 to 1.25 | 237 | 52 | 22.0 |
| .8 to .9 | 70 | 14 | 20.0 |
| .8 to 1.25 | 218 | 47 | 21.5 |
| .9 to 1.25 | 148 | 33 | 22.3 |

Aside from the value for the increase from 0.7 to 0.8 ampere, i. e., 26 per cent, all the results are remarkably constant, showing that the increase of load does not materially affect the efficiency of the body as a machine. Under all the conditions of work in these experiments the body was able to transmit about 21 per cent of the increased heat incidental to the increased load into heat of external muscular work.

In connection with these computations it should be pointed out that a possible disturbing factor is the fact that the speed per minute was not uniform with all degrees of magnetization of the field, while

it is highly probable that similar results would have been obtained in a series of experiments in which a constant speed was maintained with all grades of resistance. The experiments, unfortunately, were not made under ideal conditions for studying this point, and hence that possible error must be borne in mind.

Many other methods of using these figures in computations of the efficiency of each man and in comparing the results under different conditions might be devised, but it is believed that the comparisons here made are all that the figures justify. It is made clear from these experiments that the problem of studying the mechanical efficiency of a man is a most interesting one. So far as we are aware, no method as yet published furnishes a result as satisfactory and mathematically accurate as does the use of the bicycle ergometer and the respiration calorimeter.

## COMPARISON OF RESULTS WITH COMPUTATIONS OF MECHANICAL EFFICIENCY OF SIX-DAY BICYCLE RIDERS.

Unusual interest has been attached to the attempts to compute the heat equivalent of work done by six-day bicycle riders in their long-continued muscular strain, and also to compute the percentage efficiency of these men. R. C. Carpenter[a] computed that on the six days of the bicycle race held in December, 1898, C. W. Miller produced 4,917, 3,471, 2,917, 2,631, 2,892, and 1,786 calories of external muscular work. On these days Miller rode from 23¼ to 14¼ hours per day. In attempting to compute the mechanical efficiency of this man, Carpenter was much handicapped by the fact that no measure was available of the amount of body fat lost during the period, and although the food consumed was accurately measured, nevertheless the total energy transformations could not be accurately computed owing to the absence of data regarding the losses of body fat. Making no allowance for the body fat, Carpenter computes apparent efficiencies of over 60 per cent in the case of Miller, and of nearly 45 per cent in the case of another rider. In the experiments here reported the total heat production, as well as the energy of mechanical work, is available. Mr. Butler, a professional rider, was of the opinion that with the ergometer magnetized with a current of 0.9 ampere, the resistance was very much the same as that experienced during a six-day race, and the experiment showed that this resulted in the production of 79 calories of heat per hour in the form of external muscular work. In order to transform this amount of external muscular work, N. B. produced a total of 471 calories per hour. Assuming that similar results would have been obtained for C. W. Miller, it can be computed that if the rider remained on the wheel twenty-three hours of the day, the heat equivalent of external

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 98.

muscular work would be 1,817 calories per day. Similarly, if he produced 471 calories per hour in riding, the total heat production for the day would be 10,833 calories. This is the maximum workday of the six days that Miller rode. R. C. Carpenter's computations of the heat equivalent of work done, however, resulted in 4,917 calories instead of 1,817 calories, as found as a result of the experiments with N. B. An error so large as this is of value only in one way, namely, in showing the utter futility of attempting to compute energy transformations in experiments involving so many complex factors, such as tire, wind, and chain resistance, as are found in experiments with the professional bicycle rider.

Assuming that the work done during the six-day race is comparable to the maximum work performed by N. B., i. e., 112 calories of external muscular work per hour, and assuming that the riders remain on the wheel twenty-three hours per day, the maximum heat equivalent of external muscular work would be 2,576 calories. From the degree of exhaustion experienced by Mr. Butler on the four different days during which the bicycle was ridden at 1.25 amperes, it is highly probable that this degree of resistance is considerably greater than that when riding a track during a six-day race. As has been pointed out above, the stimulus of competition, the presence of an audience, etc., were lacking, and unquestionably Mr. Butler became more exhausted in these tests than he would have been under conditions in which there was greater psychic stimulation. It is more than probable that the estimate of 0.9 ampere resistance was very close to the resistance actually experienced in riding during a six-day race.

Irrespective of the actual amount of external muscular work performed it is seen that the results with all these riders show a remarkable constancy in that the efficiency is very close to 21 per cent, and the estimates of R. C. Carpenter, although admittedly on deficient basis, are scarcely to be considered even as approximations. This emphasizes again the great difficulties of computing the results of experiments involving factors such as those above mentioned.

# THE INFLUENCE OF MENTAL WORK ON METABOLISM.

## EARLIER INVESTIGATIONS.

That muscular work has an appreciable effect on metabolism was recognized by physiologists at a very early date. The experiments of Sanctorius[a] early in the seventeenth century show an attempt to secure accurate knowledge of physiological processes and the effects of muscular work. He recognized that a loss of body weight is possible even without appreciable muscular work, and designated the material which was lost "insensible perspiration." Observations were commonly made by early investigators of the increase in the pulse and respiration rates, the appearance of sensible perspiration, and the loss of weight following prolonged muscular effort. Lavoisier possessed a remarkably clear conception of the quantitative relations of the factors of metabolism, as is evinced by the fact that he recorded a large number of observations regarding the influence of muscular exertion on metabolism.

Lavoisier and Séguin[b] evidently believed that mental as well as muscular exertion might influence metabolism, for they considered the possibility of measuring both by the same unit, i. e., the degree of oxidation, and doubtless based their conception upon experimental evidence. The details of the methods employed by them in arriving at this conclusion are unfortunately lacking, as is the case in many other researches of Lavoisier. In their discussion, the muscular movements involved in lifting a weight, giving a lecture, and playing upon a musical instrument were considered; and as types of mental work they cited the writing of a letter, the composition of music, and the mental effort of a philosopher's reasoning.

Although of little absolute scientific value, these observations of Lavoisier and his coworker are of interest as indicating that thus early in the history of experimental science investigators were attempting to correlate mental and physical processes. As late as 1875, Liebermeister[c] sustained Lavoisier's view that mental processes are comparable with muscular movements, and in support of the theory cited an incomplete experiment on Professor Immermann which

[a] De Medicina Statica Aphorisimi. Venice, 1614.

[b] Œuvres de Lavoisier, II, p. 697.

[c] Pathologie und Therapie des Fiebers, 1875, p. 196.

implied that so far as the carbon dioxid excretion is concerned the values found seemed to substantiate Lavoisier's view. The only factor measured was carbon dioxid, and Liebermeister admits that the results are not absolutely convincing.

Physiologists for a long time attempted to establish some relation between brain and nerve activity and muscular work. When a muscle works heat is developed, and in the attempt to show the relation between brain and nerve and muscles many experiments were made for the purpose of proving that heat is developed in a nerve when stimulated. For instance, Claude Bernard,[a] using a thermo-electric needle for his measurements, reported such a development of heat.

On the other hand, Heidenhain,[b] Helmholtz,[c] and Rolleston[d] were unable to demonstrate the formation of heat in nerves.

The influence of muscular activity on body temperature has long been known, and many experiments have been made to determine whether mental work exercised a similar influence on body temperature. John Davy[e] made a large number of sublingual temperature observations on himself, and reports that during the evening sustained mental effort due to reading produced a slightly higher temperature than was normally obtained either when reading merely for amusement or when engaged in the mechanical process of copying.

When residing in the Tropics Davy[f] reports that mental exertion raised the body temperature 1.1° F.

Rumpf[g] observed that when he was reading between 9 and 12 in the evening the falling of the temperature curve which would normally be expected did not occur.

Speck[h] and Gley[i] also observed slight increases in temperature as a result of mental activity. Thus Speck reports that on three resting days his body temperature was 35.7°, 35.7°, and 35.8° C., while on days with mental activity the values were 35.9°, 35.8°, and 36° C., an increase so slight that he was inclined to attribute it wholly to minor differences in muscular activity.

Allbutt, according to Pembrey,[j] records that a long series of observations failed to indicate that mental effort affected body tem-

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[a] Vorlesungen über der Thierische Wärme. Trans. by Schuster, 1876, p. 151. Cited by Speck, Arch. Expt. Path. u. Pharmakol., 15 (1881), p. 87.

[b] Stud. Physiol. Inst. Breslau, 4 (1868), p. 250.

[c] Arch. Anat. Physiol. u. Wiss. Med., 1848, p. 158.

[d] Jour. Physiol., 11 (1890), p. 208.

[e] Phil. Trans., 1845, p. 319.

[f] Ibid., 1850, p. 443.

[g] Arch. Gesam. Physiol., 33 (1884), p. 601.

[h] Loc. cit.

[i] Compt. Rend. Soc. Biol. [Paris], 1884, p. 265.

[j] Textbook on Physiology, edited by E. A. Schäfer, New York, 1898, Vol. i, p. 808.

perature. Judging by the works cited above, the consensus of opinion, then, is that but little influence, if any, is exerted on the temperature of the body as a whole by mental activity.

Aside from the measurements of body temperature determined in the mouth or rectum, many observations have been made regarding the regional temperature of the body, and more especially of the head, recorded by some delicate means as the use of a thermal junction. The most elaborate investigation of this character with which we are familiar is that of Lombard,[a] who made an exhaustive series of experiments in which the regional temperatures of the head before, during, and after excessive mental exercise were observed. He concluded that mental effort results in a distinct rise in the temperature of the head.

A profitable line of investigation seemed to be found when a study of the amount of blood in the brain during mental work was attempted with the plethysmograph and balance table, but Mosso and Giacomiani,[b] who studied the question, reported that each movement of the body as well as mental activity produced fluctuations in the volume and pulsation of the brain. So it is difficult to determine how much of the effect is to be ascribed solely to mental work. In working on the same line of investigation, Frank[c] found that mental work caused a rise in the pulse curve in the brain, but since the respiration was similarly altered he questions whether these changes were wholly due to mental activity. Thanhoffer[d] also reports that mental activity influenced the pulse rate, while Speck,[e] on the contrary, found that the pulse and respiration rates when the mind was actively at work were not markedly different from those obtained when he was half asleep.

It is a well-known fact that mental condition resulting from shock, fear, and similar psychological phenomena may exert a marked influence on the pulse and respiration rates. Where such fluctuations occur, it is probable that the results are not the same as those induced by muscular activity, and it seems equally clear that they are of nervous rather than of mental origin.

Many observations have been based upon the assumption that there must be disintegration of brain substance as a result of brain activity. Theoretically, if mental activity is accompanied by increased metabolism, there should be an increased formation of urea, carbon dioxid, phosphoric acid, etc. Among the earliest experiments reported on this phase of the question are those of

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[a] Experimental Researches on the Regional Temperature of the Head. London, 1879.

[b] Cent. Med. Wiss., 1877, p. 343.

[c] Cited by Speck, loc. cit., p. 91.

[d] Arch. Gesam. Physiol., 19 (1879), p. 254.

[e] Loc. cit., p. 93.

Hammond,[a] who concluded that mental effort increased the quantity of urine, urea, sodium chlorid, and phosphoric and sulphuric acid.

In reporting a series of experiments made on himself, however, Speck[b] sharply criticised Hammond's work, and stated that in his opinion there is no noticeable difference in the urea output, and although due to increased mental effort, differences in the amounts of urine are found, the small amounts of urine are always of a high specific gravity, and hence there is no retention of urea and similar products. In general, Speck's experiments indicate no increase in the nitrogenous output as the result of mental work.

Oppenheim[c] made a careful study of the urea excretion during the day and night, and concluded that while it is possible so to regulate a diet as to produce a constant urea excretion, it is obvious that the processes taking place in the simple nervous system are not so regulated as to secure equality during these periods, and hence it is reasonable to assume that the mental processes are entirely independent of the proteid disintegration, at least as measured by the urea excretion.

Since mental activity is much greater during the day than during the night, at least according to all notions of psychical processes, it was believed by many that a study of the excretion during the day and night would reveal the influence of mental activity. As a matter of fact, it has been found that somewhat more than half of the total nitrogen eliminated in twenty-four hours is excreted in the urine of the day period. This may possibly be ascribed to the fact that food is ingested only during the day, though recent experiments[d] have shown that about 56 per cent of the total nitrogen in the urine voided by a fasting man appears in the urine collected between 7 a. m. and 7 p. m.

Schenk[e] found that loss of sleep did not influence noticeably the nitrogenous excretion.

Sherman[f] in studying the effect of the loss of sleep on nitrogenous metabolism reports that the influence on the nitrogen output was very slight and did not appear until the third day.

All of the earlier work on the effects of mental effort on the chemical transformations was confined to the examination of the urine for two reasons: (1) The urine was easily collected and (2) the determinations of nitrogen, phosphorus, and chlorin in urine could be easily made. There was also a notion commonly held that mental activity

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[a] Amer. Jour. Med. Sci., 1856, Apr., p. 335.

[b] Loc. cit., p. 97.

[c] Arch. Gesam. Physiol., 23 (1880), p. 455.

[d] Carnegie Inst. Washington Pub. 77.

[e] Arch. Expt. Path. u. Pharmakol., 2 (1874), p. 21.

[f] U. S. Dept. Agr., Office of Experiment Stations Bul. 121.

was in some special manner associated with the transformation of the phosphorus-containing material of the brain, and so many of the earlier investigators studied the phosphorus output also.

Mosler,[a] for example, found more phosphorus in the urine passed during the evening than in that passed during the day, and considered it to be due to more active brain work. Speck,[b] however, criticising the character of Mosler's work, showed that the results of his experiments do not indicate that an increased phosphorus elimination occurs during the evening.

During the long fasting experiment with Succi as a subject, Luciani[c] observed that mental work such as was involved in conversing and visiting with friends did not result in an increase in the nitrogenous excretion. On the other hand, as a result of the examination of the renal excretion of phosphorus, Luciani was fully convinced of the importance of this element as an index of metabolism resulting from mental processes. In some experiments on himself made in connection with Agostini, a quantitative analysis of the urine was made during two afternoon hours from 1.30 to 3.30. These were made on days when no lectures were held and on a day when they met their students and a lecture was given. Care was taken that the same quantities of food and drink were consumed on all experimental days and that the food was eaten at the same time each day. The results of these investigations, which Luciani states should be amplified, agree fully with those on Succi, showing that mental effort decreases the phosphorus content of the urine in so far as its relation to nitrogen is concerned. Luciani also cites, in confirmation of his views, work by Mendel,[c] who reports data which led him to conclude that the phosphoric acid of urine when compared to the sum of the total solids is considerably greater in the night urine than in that from the day. Further, he states that in chronic mental diseases the daily elimination of phosphoric acid in proportion to the total solids, as well as in absolute amount, is smaller than that of healthy persons under the same dietetic conditions, and that maniacs and excitable individuals show an absolute decrease in the amount of phosphoric acid in the urine. On the other hand, he noted an increase in this ratio as a result of apoplectic and epileptic attacks.

Bocker[d] in studying the relative amounts of phosphates in urine found there was a very distinct diminution of the alkaline phosphates during the night, and Mairet[e] found that during sleep both the alkaline and earthy phosphates are diminished.

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[a] Inaug. Diss., 1853, p. 12.

[b] Loc. cit., p. 100.

[c] Das Hungern. Leipzig, 1890, p. 160.

[d] Cited by Speck, loc. cit., p. 115.

[e] Compt. Rend. Soc. Biol. [Paris], 1884, p. 285.

In judging of the value of experiments on phosphorus excretion as an index of metabolism in the brain, it is necessary to take into consideration the fact that, aside from the metabolism of nucleo-proteids in the body, there is a very large store of phosphatic material in the bones which is unquestionably drawn upon and, indeed, with considerable rapidity under certain conditions. Thus a large number of fasting experiments have shown that in certain instances at least the ratio of the nitrogen excreted to the phosphorus excreted implies strongly that there was a draft upon the phosphatic material of the bones. Obviously, since there is such a reservoir of phosphorus in the body, slight changes in the excretion from hour to hour or day to day can not of themselves be taken as an index of the measure of nucleo-proteid katabolism.

The methods of studying phosphorus metabolism have not undergone material changes in recent years, being based upon titration with uranium salts, and the earlier investigations are comparable with recent results. It has, however, recently been proven that there is very little, if any, organic phosphorus in the urine, and this is an important consideration in using this element as an index of body change and indicates that to be of value experiments should include the kind and amount of phosphorus compounds rather than total phosphorus.

In all probability the sulphur output is a much more accurate index of protein katabolism than is the phosphorus output, and there has been in recent years a marked change in the interpretation of the results of analyses of urine in which sulphur was determined and an increasing belief in the importance of determining the compounds in which the sulphur is excreted. Originally investigators confined themselves to the determination of the preformed sulphates.

Baumann[a] pointed out the importance and relationship of the ethereal sulphates, and in more recent years the significance of the so-called "neutral" sulphur has become recognized. At present, then, our knowledge of the sulphur output in the urine is decidedly unsatisfactory, and in view of this fact it is questionable whether the determinations which have been reported throw any definite light on the metabolism of protein under conditions of severe mental activity.

Of earlier investigators Smith[b] observed that the volume of respiration during sleep was considerably less than that during work, and as a few years later Scharling found an increased heat production during the waking hours over sleep it was argued that the mental activity of the day, in part at least, accounted for the increased metabolism. Liebermeister[c] also found a decreased carbon dioxid production

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[a] Arch. Gesam. Physiol., 13 (1876), p. 300.

[b] Phil. Trans. London, 149 (1859), pt. 2, p. 681.

[c] Handbuch der Pathologie und Therapie des Fiebers, p. 189.

during the sleeping hours. But the more careful experiments of Johansson[a] have shown that under conditions in which all extraneous muscular activity is eliminated and the subject secures the greatest possible muscular repose the carbon dioxid production of the resting man is essentially the same whether awake or asleep.

Speck[b] used his respiration apparatus for studying the problem of the influence of mental work on metabolism. The mental work consisted in reading a scientific book, in writing up the results of experiments, and in making mathematical calculations. Experiments were also made with another subject who during the mental work period translated Latin and Greek. In all, fifty-two experiments were carried on, in which the ventilation of the lungs, the carbon dioxid produced and oxygen absorbed, as well as the number of respirations per minute and the depth of each respiration, were determined. The experiments lasted from eight to seventeen minutes. Speck concludes from the results of all these experiments that mental activity exerts no influence on the general metabolism, and that the molecular processes in the brain are either nonoxidative or their effects are so small that the experimental methods followed are not sufficiently delicate to measure them.

In a series of experiments made in cooperation with the United States Department of Agriculture and reported by Atwater, Woods, and Benedict in 1899,[c] the attempt was made to study the effect of mental effort with the aid of the respiration calorimeter, which was designed in connection with the nutrition investigations of this Department. The special feature which permitted the measurement of the income and outgo of energy had not yet been completed, so the energy balance could not be taken into account, and the work is comparable in character to that reported by Pettenkofer and Voit, in which their respiration apparatus was used. The subject of the experiments was a healthy young man, assistant in physics in Wesleyan University. During three days of the experiments he remained very quiet and endeavored to approximate a "vegetative" condition. On the next three days he spent eight hours per day studying a German treatise on physics and making computations connected with experiments with the respiration apparatus. The average nitrogen and carbon output per twenty-four hours are given in the following table:

*Average daily output of nitrogen and carbon in rest and mental work.*

| Period. | Duration. | Nitrogen. | Carbon. |
|---|---|---|---|
| | *Days.* | *Grams.* | *Grams.* |
| Mental work | 3 | 13.1 | 241.0 |
| Rest | 3 | 12.5 | 248.4 |

[a] Skand. Arch. Physiol., 8 (1898), p. 85.

[b] Arch. Expt. Path. u. Pharmakol., 15 (1881), p. 128. See also Physiologie des Menschlischen Athmens. Leipzig, 1892, p. 204.

[c] U. S. Dept. Agr., Office of Experiment Stations Bull. 44.

It is evident, therefore, that in this experiment the mental effort resulted in no marked or noticeable alteration in the general metabolism, for while there was a slightly higher output of nitrogen during the mental work period, there was a somewhat smaller output of carbon.

Of interest in this connection are the experiments reported by Obici,[a] who notes that the mental effort accompanying mathematical calculations resulted in an increased respiration rate and a deeper inspiration, and thus the lungs are more completely ventilated than usual. When the subject is mentally exhausted, the rate and volume of respiration decrease markedly.

Not only have attempts been made to study the effect of mental strain by the methods above referred to, but the natural supposition that the fatigue resulting from muscular work was properly comparable with that resulting from mental effort has been the basis of another line of investigation in which an ergograph of special construction has been used to measure the effect on fatigue of a variety of conditions. The well-known work of Mosso and Maggiora proved conclusively that mental exertion produces not only psychical weariness, but results also in a distinct loss of muscle power. Thus in a series of experiments on Doctor Maggiora, Mosso[b] showed by his ergograph that the onset of fatigue was very much more rapid after a severe mental strain, such as that accompanying the questioning of candidates in an examination. Furthermore, the return to the normal condition was delayed at least two hours after the mental effort and probably considerably longer. Thus scientific research verifies the popular conception that mental exertion results in a marked lowering of the muscular power.

## MEASUREMENTS OF MENTAL WORK.

While it is possible by means of the ergograph to show definitely the influence of intellectual activity on muscular power and the onset of fatigue, the problem of demonstrating the influence of intellectual activity upon any of the ordinary processes of metabolism is extremely complex, since it is evidently unscientific to rely on personal impressions as to degree of fatigue and exhaustion. For a satisfactory study of the problem it is necessary, in order to obtain conclusive results, to measure first the degree of mental activity and second to measure the products of metabolism with such a degree of refinement as to show the influence of a factor which must be small in comparison with the better understood factors—muscular work, for instance—which influence anabolic and katabolic body processes.

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[a] Riv. Sper. Freniatria, 27 (1901), Dec.; abst. in Jahresber. Tier-Chem., 32 (1902), p. 621.

[b] La Fatigue Intellectuelle et Physique. Paris, 1900, p. 152.

The ordinary methods of the psychologist for studying the intensity and degree of mental exertion depend upon comparative measurements of the relative rapidity with which columns of figures can be added, or words or passages memorized, or some similar test.

An attempt to measure mental activity through muscular work was also made in Loeb's laboratory by Jeanette C. Welch,[a] in connection with a series of experiments to study the so-called "constant of attention," using a dynamograph devised by Loeb.

But such tests in general occupy but a short space of time, and measurements of metabolic activity are as a rule unreliable for such short periods. Consequently the usual tests of the psychologist can not well be applied in studies of the effect of mental work on metabolism, and it becomes necessary to use some method of measurement which will cover a considerable time.

From the results of previous investigations, which have been summarized in the foregoing pages, it is clear that the influence of mental effort on metabolism is in all probability not great, as compared with other factors which affect it, and hence in planning a study of this question it is desirable to employ some form of mental effort that will be at once long continued and intense, and thus attempt to exert the maximum effect on metabolism and to use a method which is accurate and suitable for measuring small changes in metabolism. Theoretically, intense application to the study of certain mathematical problems might at first sight appear best adapted for long-continued mental effort, or some similar task which involves concentration of mental powers and is considered difficult by the subject.

In the experiments reported beyond, the subjects, during the mental work period, were engaged in answering the questions in written examinations in a number of different university subjects, and the work may fairly be regarded as at least reasonably exacting for the average student.

## METHODS OF MEASURING RESULTS OF MENTAL EFFORT.

The previous studies of Mosso, and of psychologists such as Kraepelin, have shown the results of mental effort in diminishing muscular strength as measured by the ergograph and the retarding effect of mental activity as shown by a lengthened reaction time. But for reasons already stated such experiments do not seem adequate, and it seems certain that a study of the effect of mental activity on metabolism is of especial importance and likely to give results of value. Metabolic transformations can be measured in two ways: (1) By the results of chemical changes, oxidative processes, cleavage, changes in the body, etc.; and (2) by the energy transformations resulting from the katabolic processes.

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[a] Amer. Jour. Physiol., 1 (1898), p. 283.

## CHEMICAL TRANSFORMATIONS.

For purposes of study we can consider the body as composed chiefly of the three chemical compounds, protein, fat, and carbohydrates. A considerable number of other chemical compounds are also present, but in much smaller amounts. It has commonly been supposed that the best index of protein katabolism is the excretion of nitrogen in the urine, although in recent years the great significance of the partition of the nitrogen excreted in the urine has become more apparent. A study of the transformations of protein may be made with considerable accuracy and with no especially complex apparatus by collecting the 24-hour quantity of urine and subjecting it to chemical analysis. But the transformations of fat and carbohydrates can be studied only by an apparatus permitting an accurate measurement of the respiratory gases, and therefore it is necessary to utilize a much more complex apparatus, such as the respiratory apparatus of Zuntz-Geppert or the larger respiration chambers of the Pettenkofer and Voit type.

From the well-known functions of the brain it is logical to suppose that mental effort would result in increased chemical transformations in the brain substance itself. It has been the common belief that mental processes involve not only the disintegration of ordinary flesh protein, but also of the nucleo-proteins, lecithin, kephalin, etc., of the brain. These compounds are especially rich in phosphorus, and hence much significance has been laid upon the elimination of phosphorus in the urine. The experimental evidence thus far presented, however, fails to establish any relation between mental activity and phosphorus metabolism.

Protein contains sulphur, and this element also has been studied as an index of protein katabolism, and there are reasons for believing that such a method is especially desirable under suitable conditions.

A critical study of the nitrogen, sulphur, and phosphorus output shows that the amount excreted is a result of a series of very complex changes. With regard to the element nitrogen, for example, the work of Folin has shown that variations in diet produce markedly different nitrogenous excretions. In fact, the differences are so great as to lead Folin to contend that there are two kinds of protein katabolism, the so-called endogenous and exogenous. All of the evidence indicates a much more complex katabolism than the simple urea determinations of the earlier writers would imply, and while it is very evident that the total nitrogen output as determined by the Kjeldahl method is a much better index of protein katabolism than was the total urea determination as made by the faulty and defective Liebig method, yet in any study in which the influence of a subtle factor such as mental effort is to be studied, a much more satisfactory and delicate measure of metabolism must be used.

Furthermore, while the total nitrogen output is of value in indicating the loss of this chemical element to the body, it is of little value for the study of the minor factors influencing metabolism and especially the intermediary metabolism. A careful study, by modern methods, of the purin metabolism may ultimately throw some light on the disintegration products of protein katabolism as affected by mental exertion. In connection with the series of mental tests here reported it was impracticable to make such a study, as it would involve the consumption of a carefully selected and constant diet which should be adhered to for a sufficient period to secure a constant purin output, and under the experimental conditions this was not possible.

It is recognized by all students of metabolism that the total metabolism can best be studied by measuring the respiratory gases. Fortunately, by means of the respiration calorimeter in the chemical laboratory of Wesleyan University, this method of study was possible. The apparatus permits the determination of the water vaporized from the lungs and skin, the carbon dioxid output, and the oxygen intake. The periods during which the subjects were studied in the respiration calorimeter covered three hours and, since check tests had shown the apparatus to be extremely accurate for experiments of this duration, it is believed that the recorded measurements of water output and carbon dioxid elimination are as accurate as could be desired.

Unfortunately, owing to the rapidity with which the tests had to be made, the large number carried on, and similar causes, the oxygen determinations in some of the experiments were unsatisfactory, though in the majority of cases they are regarded as trustworthy. Although the effects of various well-known factors on protein metabolism are, in all cases, slow in manifesting themselves, it is fortunate that the factors affecting general metabolism are almost invariably characterized by marked changes in the respiratory gases, and indeed almost immediately after the factor has begun to influence the transformation. Perhaps the most striking evidence of this is offered by the experiments of Bowen and Higley,[a] who noted that intense muscular work resulted in a noticeable increase in the carbon dioxid output within twenty seconds after the effort began. While the extreme sensitiveness of the respiratory gases to the factors influencing metabolism is on the one hand of decided advantage in studying the influence of a factor admittedly so subtle as is that of mental exertion, yet this extreme sensitiveness also has a certain disadvantage, for it is likewise susceptible to the influence of the slightest muscular activity, the work of digestion, etc. Hence it is of vital importance that all conditions other than the one studied be constant in all experiments on the influence of mental work. The most marked influence on the

[a] Amer. Jour. Physiol., 12 (1904), p. 311.

respiratory exchange is produced by muscular activity, and for this reason especial efforts were made in our experiments to control this factor, and probably the routine followed resulted in a reasonably close approximation to constancy, but the diet, the degree of nervousness, sleepiness, etc., of the different subjects could not be controlled. It is furthermore highly probable that during the periods when the examinations were made the subjects were influenced more by irregular hours of sleep, nervousness, and possibly in some cases by irregularity of meals, than during any other time of the year. These facts are mentioned to make it clear that it is recognized that the conditions for conducting these experiments were by no means ideal, yet they were as favorable perhaps as could be expected and all possible care was taken to avoid error. The data are given in detail and show the actual conditions under which the experiments were conducted.

## MEASUREMENT OF HEAT.

The importance of a measurement of heat production in studying the possible influence of mental effort on metabolism may be realized when the popular notion is recalled that during a severe mental test, such as an examination in some difficult subject, individuals have a distinct feeling that they are working hard and perspire freely at times, and that consequently it is conceivable that extreme mental effort might affect the heat output. The measurement of heat radiated from the body has not commonly been reported in experiments on man, but the respiration apparatus here used was so combined with calorimetric devices as to permit the measurement of the heat production and respiratory products simultaneously. While the respiratory exchange and heat production apparently go hand in hand, strictly speaking, this is not always true, for when fat is burned much more heat is eliminated per gram of carbon dioxid liberated than when carbohydrates are burned. This fact is of importance in interpreting the results of the experiments, especially those in which diets of different nature are used, by devising a routine of muscular movements which each subject followed, and determining the respiratory exchange alone might not show the influence of mental exertion, since such influence might be masked by the influence of the variations in the diet. On the other hand, the heat production, while unquestionably affected somewhat by the ingestion and assimilation of food, is by no means as markedly influenced as is the respiratory exchange.

A measure of the heat elimination alone does not give a true index of the heat production, for it may happen in some instances that the body temperature is lowered noticeably during an experimental period, thus indicating a loss of heat from the body which was not

necessarily produced during the period. Conversely, an increase in the body temperature may result in a storage of heat in the body which is not measured by the calorimeter, though, strictly speaking, it was produced during the experimental period. In accurate experiments, therefore, it is necessary to take account not only of the heat elimination, but also of the heat production. This involves a careful measurement of body temperature and body weight. The loss of weight of material during a period indicates the cooling of a certain mass of material from the temperature of the body to that of the calorimeter, but does not imply an actual heat production during the period of this amount of heat. For measuring body temperature it has been the custom for many years in the metabolism experiments conducted with the respiration calorimeter to use a delicate electrical resistance thermometer which can be inserted in the rectum and permits the making of records of the body temperature deep in the trunk. It was found impracticable to employ this method in the experiments here reported, and consequently the subjects at stated periods of the day took their sublingual temperature with a mercurial clinical maximum thermometer, and these resulting records of temperature changes were used in computing the heat production.

## GENERAL PLAN OF THE EXPERIMENTS.

In the experiments here reported the plan was adopted of comparing the general metabolism, including the heat production, during a period of intense mental effort with the general metabolism and heat production during a period of comparative mental rest. The respiration calorimeter at Wesleyan University was used for obtaining the measurement of carbon dioxid, water, oxygen, and heat. Incidentally, observations regarding body temperature, pulse rate, loss in body weight, and personal impressions were likewise recorded in all the experiments. No analyses of the urine were made, but it is believed that the determination of the respiratory products and the heat production sufficed for the purpose in hand and furnished as accurate a measure of metabolism as it was possible to obtain under the circumstances.

The period of mental activity involved was in all cases the three hours devoted to taking the regular collegiate midyear examinations in some special subject. During these examinations the men are subjected to a two to three hour test of their mental powers, and there is, as a rule, a great stimulus to concentrated and continued mental effort. There is presumably more uniformity in the mental condition of a number of students under examination than is readily obtainable in any series of artificial and more or less unfamiliar conditions as could be readily obtained by other means. A large num-

ber of men (twenty-two) was included in this study, with the idea of eliminating the personal equation in so far as possible and of including tests of memory in which originality should play an important rôle.

The periods in which the effects of mental work were studied were followed after an interval by control tests in which the mental work was of the sort which is generally considered light, the subjects being engaged in copying something in which they were not especially interested or in reading something demanding no concentrated mental effort.

The respiration calorimeter, as has been explained in earlier publications of this series,[a] is equipped with a chair, table, and other conveniences and is lighted by a window in the front. As regards comfort, indeed, the subjects were under no abnormal conditions. They were, to all intents and purposes, simply taking an examination of their college in a small room where they could give their whole thought to it.

Each subject entered the calorimeter chamber a little over an hour before the experiment began. Previous to this he had been given as much water as he wished, and had been requested to defecate if possible, in order to avoid defecation during the examination period. Aside from the permanent fixtures inside the chamber, such as the shelves and telephone, a table of convenient height and a comfortable wooden armchair were provided, so as to enable the subjects to take their examinations under favorable conditions as regards physical comfort. The table and chair were so placed that the light from the window entered at the left. A previously weighed bottle containing drinking water was placed in the chamber, as were also two bottles for the collection of urine.

The subject, wearing his ordinary clothing, entered the chamber and after being weighed while seated in the chair which was swung from a balance scale outside the chamber, assumed a comfortable position and read or wrote until time for the examination to begin.

A few moments before the experimental period began determinations of the amounts of carbon dioxid and residual water vapor in the air of the calorimeter system were made, and five minutes before the experimental period the subject was asked to place a clinical thermometer in the mouth under the tongue. Immediately after the experimental period began the subject went to the opening of the calorimeter through which food and minor articles are passed, placed the clinical thermometer in it, and removed therefrom the examination paper. He then resumed his chair and immediately began to write the answers to the examination questions.

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[a] U. S. Dept. Agr., Office of Experiment Stations Buls. 63, 109, 136, 175.

## PULSE RATE.

At the time these experiments were made a pneumograph for obtaining the pulse rate was not in use by us, and so the subjects were instructed to count the radial pulse in the left arm, using a stop watch and recording the number of beats and the seconds in fractions. Subsequently all the observations were computed on the basis of the number of beats per minute. The pulse rate was taken several times during the three-hour period, although no direct instructions regarding the times for taking the pulse rate were given.

## GENERAL IMPRESSIONS.

In order to obtain as accurately as possible an estimate of the mental condition of the subjects, they were requested to note down from time to time their personal impressions regarding comfort or discomfort, ventilation, temperature, noise or distraction, and light.

## CHARACTER OF FOOD PRECEDING THE EXPERIMENTS.

Most of these experiments were made within two hours after a meal was taken, and hence it seemed desirable to have a record, even though it be but approximate, of the kind and amount of food eaten at the preceding meals and the time the meals were taken. From the well-known effect of the ingestion of food on the respiratory quotient the data thus secured are of much importance in interpreting the respiratory exchange.

At the conclusion of the experiment the body temperature and the body weight were again taken, after which the subject left the chamber.

## SUBJECTS OF THE EXPERIMENTS.

The subjects of these experiments were all healthy young men, ranging from 17 to 29 years of age, students in Wesleyan University, and while none of them had had practical experience as subjects of respiration calorimeter experiments, all nervousness or apprehension had disappeared as the result of the preliminary sojourn of an hour in the chamber. We believe that these men were in as normal a state of mind as is the ordinary college student on similar occasions. As a group they represented probably a fair average of the student body. In selecting the men care was taken to avoid those who were uncertain as to whether they could meet the requirements of the examination, and hence the element of extreme apprehension commonly experienced by such students, an element which might well interfere seriously with a study of the problems involved, was eliminated.

On the other hand, in order to secure a mental stimulus and induce a strong mental effort the majority of the men selected were those who were anxious for scholarship prizes or some similar college honor. In spite of these attempts to secure the greatest mental exertion with freedom from apprehension, it will be noted in reading the record of the mental impressions of the various men that these factors did enter at times into many of the experiments.

Since the metabolism is largely proportional to the body weight of the individual, a table of statistics of the average weight at the time and size of the subjects is given in the following table, together with the age and height of each of the subjects:

*Statistics of age, height, and average weight of subjects.*

| No. | Subject. | Age. | Height. | Weight. |
|---|---|---|---|---|
| | | | | *Kilograms.* |
| 1 | J. A. R | 23 years 6 months | 5 feet 11 inches | 59.3 |
| 2 | H. D. A | 21 years 5 months | 5 feet 11¼ inchs | 65.1 |
| 3 | H. G | 22 years 5 months | 5 feet 3 inches | 49.2 |
| 4 | F. N. C | 19 years 1 month | 5 feet 6 inches | 57.8 |
| 5 | J. V. C | 22 years | 5 feet 8 inches | 63.2 |
| 6 | A. M | 21 years 6 months | 5 feet 9 inches | 67.2 |
| 7 | F. E. R | 20 years 5 months | 5 feet 6 inches | 51.5 |
| 8 | J. W. H | 29 years | 5 feet 9 inches | 60.6 |
| 9 | C. A. R | 18 years 10 months | 5 feet 8½ inches | 58.2 |
| 10 | G. H. H | 21 years 3 months | 5 feet 4 inches | 51.6 |
| 11 | H. L. W | 26 years 11 months | 5 feet 4½ inches | 52.0 |
| 12 | D. R. F | 23 years | 5 feet 8 inches | 62.7 |
| 13 | J. N. T | 21 years 10 months | 5 feet 8 inches | 62.7 |
| 14 | H. C. A | 21 years 4 months | 5 feet 7¾ inches | 58.7 |
| 15 | F. C. B | 23 years 6 months | 6 feet | 72.6 |
| 16 | G. E. H | 27 years | 5 feet 10½ inches | 63.2 |
| 17 | N. M. P | 21 years 2 months | 5 feet 10½ inches | 70.0 |
| 18 | G. W. S | 20 years | 5 feet 8 inches | 52.2 |
| 19 | A. G | 24 years | 5 feet 7 inches | 61.3 |
| 20 | H. L. K | 23 years 4 months | 5 feet 5½ inches | 57.0 |
| 21 | G. G. R | 19 years 10 months | 5 feet 10 inches | 77.2 |
| 22 | E. M. S | 27 years | 5 feet 8¾ inches | 64.1 |

## STATISTICS OF THE MENTAL WORK EXPERIMENTS.

The detailed statistics of the experiments are given in the following pages. The character of the diet before the experiment, the personal impressions of the subject during the periods, the pulse rate, body temperature, and body weight at the beginning and end of the experimental period, are all given as supplementary evidence bearing on the general question of metabolism.

### METHOD OF CALCULATION OF BODY WEIGHT TO PERIODS.

The procedure of calculating the body weight for the beginning and end of the periods in these experiments needs some explanation and was as follows:

There were two weights taken of the man, one at the time he entered the calorimeter and the other immediately after the experiment was finished. From the difference in time of these two weights and the change in weight the amount of loss from the time

of the first weighing until the beginning of the period was calculated. Also the amount lost from the end of the last period to the last weight was calculated. This method of calculation assumes that the rate of loss at the beginning of the period is practically the same as at the end. This is probably not true, but the actual difference between the loss of weight calculated by the above method and the actual loss is so small as to be negligible. In case urine was passed or water drunk, the weight of urine was added to the end weight and the amount of water consumed subtracted from the end weight, so as to obtain what would correspond to the respiratory loss. The loss of body weight as calculated by this method is less than would be obtained if it were calculated by the respiratory loss. The probable reason for this is because the materials inside the calorimeter, such as the table and chair, lose weight, presumably water, and this loss would be calculated in the absorption of water. An example of the above method of calculation is given below. The subject J. A. R. in mental work experiment No. 1 weighed at 8.04 a. m. 59.367 kilograms. At 12.10 p. m. he weighed 59.192 kilograms. There was thus a loss in weight of 0.175 kilogram in 246 minutes. The first period began at 8.59 a. m. Therefore the difference in time between the time of the first weighing and the beginning of the first period was 55 minutes, and the amount of loss would be $\frac{55}{246} \times 0.175$ kilogram. This gives 0.039 kilogram as a loss from 8.04 to 8.59 a. m. Subtracting this from the weight at 8.04 a. m. we have 59.328 kilograms. Therefore the body weight at 8.59 a. m., at the beginning of the first period, is 59.328 kilograms. Similarly, the last weight was taken at 12.10 p. m., and the end of the last period was at 11.59 a. m. Therefore there was a difference of 11 minutes, and $\frac{11}{246} \times 0.175$ kilogram gives 0.008 kilogram as the loss in weight between 11.59 a. m. and 12.10 p. m. The subject weighed at 12.10 p. m. 59.192 kilograms. Therefore at 11.59 a. m. he would weigh the above weight +0.008, giving 59.2 kilograms.

Copies of the examination papers are not included in this report, though they have been kept on file. As has been stated previously, it is believed that they involved concentrated mental effort on the part of the subjects.

### MENTAL WORK EXPERIMENT No. 1.

The experiment was made with J. A. R. on the forenoon of February 8, 1905. Breakfast preceding the experiment consisted of an average-sized dish of oatmeal with sugar and milk, a large slice of bread, and 2 heaping tablespoonfuls of beef and potato hash.

The record of impressions kept by the subject stated that he suffered no inconvenience during the period in the calorimeter and was not disturbed by the noise of the blower which forces the ventilating air

current through the respiration chamber. He had just time during the experimental period to complete his examination paper and reread it. No water was drunk and no urine was passed during the experiment.

The pulse rate was taken a number of times and was as follows: 8.52 a. m. 97, 9.57 a. m. 83, 10.02 a. m. 87, 10.05 a. m. 85, 11.36 a. m. 73, 11.39 a. m. 75, and 11.41 a. m. 74.

The body temperature at 8.59 a. m., shortly after the beginning of the experimental period, was 98.5° F. and at 11.59 a. m., shortly before the close of the experimental period, it was 97.5° F.

The body weight at the beginning of the experiment, 8.04 a. m., was 59.367 kilograms, and at the close of the period, 12.10 p. m., it was 59.192 kilograms.

The subject took an examination in physics (thermodynamics), writing 1,260 words. When the examination papers were corrected it was found that he had secured first grade.[a]

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 1.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.59 to 10.29 a. m | 48.38 | 51.17 | 40.01 | 144.30 | ........... |
| 10.29 to 11.59 a. m | 52.18 | 49.96 | 37.03 | 144.44 | ........... |
| Total for 3 hours | 100.56 | 101.13 | 77.04 | 288.74 | 0.128 |

## MENTAL WORK EXPERIMENT No. 2.

The experiment was made with H. D. A. on the afternoon of February 8, 1905. Dinner eaten before the experimental period consisted of 6 tablespoonfuls of vegetable soup, a slice of roast beef with mashed potatoes, and tomatoes, one-sixth of an apple pie, and a medium-sized cup of coffee with 3 teaspoonfuls of sugar, and about 2 teaspoonfuls of sugar were also eaten on the pie.

The record kept by the subject shows that he found the air rather poor at first, but after a little it was satisfactory, the light was fair, the temperature of the respiration chamber comfortable, and the noise of the blower, though noticeable, was not disturbing. The actual work involved in taking the examination required 137 minutes, though he was engaged in writing for the whole experimental period of three hours.

The pulse rate taken at different times was as follows: 1 p. m. 83, 1.30 p. m. 77, 1.58 p. m. 82, 2.30 p. m. 79, 3 p. m. 72, 3.30 p. m. 73, 4 p. m. 69, and 4.30 p. m. 69.

[a] By first grade is meant the mark obtained on the examination. Grades in examinations range from 1 to 5, 1 being the highest obtainable and 5 indicating that the subject has not passed the examination. A mark of 4 corresponds to 60 per cent.

At the beginning of the experiment, 2.03 p. m., the body temperature was 98.7° F. and at the end of the period, 5.03 p. m., it was 98.3° F.

The body weight at 12.49 p. m. was 65.266 kilograms and at the close of the experiment, 5.13 p. m., 65.01 kilograms.

The subject took the same examination (thermodynamics) as the subject of experiment No. 1, writing 1,550 words, in answering the examination questions, and secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 2.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.03 to 3.33 p. m | 69.65 | 41.20 | .......... | 178.34 | .......... |
| 3.33 to 5.03 p. m | 63.85 | 52.80 | 48.00 | 164.88 | .......... |
| Total for 3 hours | 133.50 | 94.00 | .......... | 343.22 | 0.174 |

## MENTAL WORK EXPERIMENT No. 3.

The experiment was made with H. G. on the forenoon of February 9, 1905. Breakfast before the experimental period consisted of a shredded-wheat biscuit, a cup of coffee, a biscuit, 2 tablespoonfuls of sugar, and one-half glass of milk.

As shown by the record which the subject kept, he became accustomed to his surroundings soon after entering the respiration chamber and was comfortable, although he was a little drowsy at first, owing to the rather high temperature of the respiration chamber at the beginning of the experimental period. He did not consider the examination difficult and was in no way disturbed by taking it in the respiration chamber.

The pulse rate as recorded at different times during the experimental period was as follows: 8.10 a. m. 84, 8.45 a. m. 89, 9.25 a. m. 84, 10.05 a. m. 76, 10.25 a. m. 74, 10.55 a. m. 72, 11.30 a. m. 70, 11.45 a. m. 68, and 12 noon 67.

The body temperature, which was taken at the beginning and end of the experimental period, was 99° F. at 9.04 a. m. and 98.2° F. at 12.04 p. m.

The body weight at 8 a. m. was 49.279 kilograms and at 12.12 p. m. it was 49.103 kilograms.

The subject took an examination in evolution, and in answer to ten questions wrote 2,000 words. When the examination papers were corrected he was given third grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 3.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.04 to 10.34 a. m. | 52.64 | 44.62 | 45.62 | 140.91 | |
| 10.34 a. m. to 12.04 p. m. | 53.48 | 37.32 | | 126.17 | |
| Total for 3 hours | 106.12 | 81.94 | | 267.08 | 0.125 |

## MENTAL WORK EXPERIMENT No. 4.

The experiment was made with F. N. C. on the afternoon of February 9, 1905. Lunch before the experimental period consisted of a little roast-beef hash with creamed potatoes, a slice of bread and butter, and a portion of apple tapioca pudding.

The subject found the air and light in the respiration chamber satisfactory and was not disturbed by the sound of the rotary blower, though he found that the rattling of the metallic shields used to regulate the heat absorption system was somewhat disturbing. In general, he found the confinement in the respiration chamber rather monotonous, though he states that he could as well take the examination there as in the regular class room.

The pulse rate was recorded several times as follows: 2.08 p. m. 66, 2.45 p. m. 72, 3.18 p. m. 72, 3.45 p. m. 66, 4.12 p. m. 60, 4.40 p. m. 66, and 4.55 p. m. 72.

The body temperature was taken at the beginning and at the close of the experimental period, being 98.1° F. at 2.05 p. m. and 97.8° F. at 5.05 p. m.

The body weight at 1.05 p. m. was 57.943 kilograms and at 5.13 it was 57.75 kilograms.

The subject took an examination in chemistry, writing about 1,200 words and securing second grade. The details of the experiment follow:

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 4.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.05 to 3.35 p. m. | 57.93 | 54.18 | 39.74 | 158.55 | |
| 3.35 to 5.05 p. m. | 53.85 | 51.91 | 37.34 | 152.10 | |
| Total for 3 hours | 111.78 | 106.09 | 77.08 | 310.65 | 0.140 |

## MENTAL WORK EXPERIMENT No. 5.

The experiment was made with J. V. C. on the forenoon of February 10, 1905. Breakfast before the experimental period consisted of a dish of oatmeal with sugar and milk, a small plate of hash, and a cup of coffee with sugar and milk.

Though a little drowsy at first, the subject states that he was perfectly comfortable in the respiration chamber during the experimental period. He drank 42 cubic centimeters of water.

The pulse rate as taken at intervals was as follows: 8.10 a. m. 82, 8.58 a. m. 77, 10.03 a. m. 71, 10.30 a. m. 69, 11 a. m. 67, and 12 noon 73.

Records for body temperature were, at 9.01 a. m. 98.3° F., and at 12.01 p. m. 98.3° F.

The body weight was 63.306 kilograms at 7.57 a. m. and 63.121 kilograms at 12.09 p. m.

The subject took an examination in English literature, writing 2,200 words, and secured second grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 5.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.01 to 10.31 a. m. | 63.59 | 52.03 | 44.22 | 153.65 | |
| 10.31 a. m. to 12.01 p. m. | 67.70 | 49.57 | 44.18 | 148.93 | |
| Total for 3 hours | 131.29 | 101.60 | 88.40 | 302.58 | 0.132 |

## MENTAL WORK EXPERIMENT No. 6.

The experiment was made with A. M. on the afternoon of February 10, 1905. Dinner, which was eaten shortly before the experiment began, consisted of two small pieces of roast beef, a little potato, four slices of bread, a piece of squash pie, and a cup of coffee.

Though a little warm at first, the subject was soon comfortable and remained so throughout the experimental period. He states that he found the examination very long, though not particularly difficult, and that he was so busily engaged that he perspired noticeably. During the experimental period he drank 61 cubic centimeters of water.

The pulse rate as recorded at different times was as follows: 1.45 p. m. 87, 3 p. m. 79, 4 p. m. 77, and 4.30 p. m. 77.

The body temperature at 2.01 p. m. was 99.2° F. and at 5.01 p. m. 98.9° F.

The body weight was taken twice, being 67.285 kilograms at 12.53 p. m. and 66.942 kilograms at 5.14 p. m.

The subject took the same examination in English literature as the subject in experiment No. 5, wrote 2,400 words, and obtained second grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 6.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.01 to 3.31 p. m. | 74.89 | 59.83 | .......... | 189.78 | .......... |
| 3.31 to 5.01 p. m. | 73.87 | 54.11 | 34.36 | 170.33 | .......... |
| Total for 3 hours | 148.76 | 113.94 | .......... | 360.11 | 0.237 |

## MENTAL WORK EXPERIMENT No. 7.

The experiment was made with F. E. R. on the forenoon of February 11, 1905. Breakfast before the experimental period consisted of a small dish of oatmeal and a cup of coffee with milk and sugar.

Though rather nervous at first, the subject states that he soon became quite collected and felt that he could take the examination as easily as in the class room. He found the temperature of the respiration chamber a little too high for comfort.

The pulse rate, which was taken at intervals, was as follows: 7.56 a. m. 58, 8.07 a. m. 94, 8.18 a. m. 104, 8.44 a. m. 101, 8.55 a. m. 101, 10.35 a. m. 88, 11.06 a. m. 89, 11.29 a. m. 88, 11.47 a. m. 91, and 12.03 p. m. 90.

The body temperature at 9.01 a. m. was 99.7° F. and at 12.01 p. m. 99.4° F.

The body weight at 7.52 a. m. was 51.618 kilograms and at 12.09 p. m. 51.409 kilograms.

The subject considered that the examination paper in psychology with which he was engaged was rather difficult and required considerable thought. He secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 7.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.01 to 10.31 a. m. | 61.45 | 45.17 | 33.87 | 143.45 | .......... |
| 10.31 a. m. to 12.01 p. m. | 58.13 | 43.90 | 36.35 | 134.81 | .......... |
| Total for 3 hours | 119.58 | 89.07 | 70.22 | 278.26 | 0.146 |

## MENTAL WORK EXPERIMENT No. 8.

The experiment was made with J. W. H. on the afternoon of February 11, 1905. Dinner taken shortly before the experimental period consisted of 2 slices of boiled ham with cabbage and potatoes, 1¼ slices of bread and butter, a piece of apple pie, and 1 large cup of coffee.

The subject states that he felt comfortable all the time he was in the respiration chamber, though he was rather tired from the university work in which he was engaged on preceding days. He drank 191 cubic centimeters of water during the experiment.

The pulse rate was recorded as follows: 1.20 p. m. 87, 2 p. m. 96, 3 p. m. 87, 4 p. m. 75, and 4.50 p. m. 74.

The body temperature at 1. 55 p. m. was 98.9° F. and at 4.55 p. m. it was 98° F.

The body weight at 12.45 p. m. was 60.688 kilograms and at 5.02 p. m. 60.406 kilograms.

In answering the examination questions in physics with which he was engaged the subject wrote 1,150 words and secured third grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 8.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 1.55 to 3.25 p. m | 64.50 | 61.28 | 56.17 | 180.28 | |
| 3.25 to 4.55 p. m | 73.09 | 55.59 | 40.53 | 168.16 | |
| Total for 3 hours | 137.59 | 116.87 | 96.70 | 348.44 | 0.197 |

## MENTAL WORK EXPERIMENT No. 9.

The experiment was made with C. A. R. on the forenoon of February 13, 1905. Breakfast shortly before the experimental period consisted of a large glass of milk and a dish of cereal breakfast food.

The subject states that though he had had little sleep on the night preceding the experiment, and so was rather tired, he did not find the confinement in the respiration chamber at all disagreeable and considered the conditions entirely satisfactory for taking an examination.

The pulse rate as recorded was as follows: 8.30 a. m. 90, 9 a. m. 82, 9.25 a. m. 82, 9.45 a. m. 78, 10.10 a. m. 76, 10.45 a. m. 76, 11.15 a. m. 72, 11.45 a. m. 70, and 12 noon 70.

The body temperature at 9 a. m. was 99.2° F. and at 12 noon 98° F.

The body weight was 58.318 kilograms at 7.56 a. m. and 58.13 kilograms at 12.09 p. m.

The subject took an examination in French, securing second grade. He wrote 1,800 words.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 9.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9 to 10.30 a. m | 54.92 | 48.90 | 37.11 | 160.85 | .......... |
| 10.30 a. m. to 12 noon | 57.86 | 43.24 | .......... | 149.13 | .......... |
| Total for 3 hours | 112.78 | 92.14 | .......... | 309.98 | 0.133 |

## MENTAL WORK EXPERIMENT No. 10.

The experiment was made with G. H. H. on the forenoon of February 14, 1905. Breakfast preceding the experiment consisted of a dish of dry cereal breakfast food, with sugar and milk, 2 slices of corn bread, and a glass of milk.

Though somewhat nervous, owing to confinement in the respiration chamber, the subject felt that he did as well with the examination as he could have done under usual circumstances in the class room. He considered the examination rather difficult.

The pulse rate was recorded as follows: 9.10 a. m. 114, 10 a. m. 124, 10.35 a. m. 118, 11.15 a. m. 106, 12 noon 120, and 12.25 p. m. 119.

The body temperature was not taken.

The body weight at the beginning of the experiment, 8.23 a. m., was 51.656 kilograms and at the close, 12.37 p. m., 51.484 kilograms.

The subject of the examination paper with which he was engaged was economics, and second grade was obtained.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 10.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.23 to 10.32 a. m | 38.05 | 36.19 | 32.72 | 107.35 | .......... |
| 10.32 a. m. to 12.32 p. m | 66.15 | 62.29 | 45.23 | 177.09 | .......... |
| Total for 3 hours 9 minutes | 104.20 | 98.48 | 77.95 | 284.44 | 0.141 |

## MENTAL WORK EXPERIMENT No. 11.

The experiment was made with H. L. W. on the afternoon of February 14, 1905. Dinner preceding the experimental period consisted of a small portion of roast beef, a small potato with butter, a portion of tomatoes, and an apple dumpling.

The subject found the sound of the blower and other machinery in the respiration chamber rather soothing than otherwise. He finished the examination paper and read it over carefully about an hour before the close of the experimental period and rested until the experiment closed.

The pulse rate was recorded a number of times as follows: 1.30 p. m. 76, 2.14 p. m. 86, 2.45 p. m. 88, 3.25 p. m. 88, 4 p. m. 72, 4.34 p. m. 72, and 4.55 p. m. 69.

The body temperature at 2.02 p. m. was 99.5° F. and at 5.02 p. m. 98.6° F.

The body weight at 12.54 p. m. was 52.046 kilograms and at 5.11 p. m. 51.855 kilograms.

The subject was engaged with an examination paper on economics and secured third grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 11.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.02 to 3.32 p. m | 62.24 | 46.44 | 38.58 | 148.52 | .......... |
| 3.32 to 5.02 p. m | 61.66 | 39.22 | 32.05 | 144.99 | .......... |
| Total for 3 hours | 123.90 | 85.66 | 70.63 | 293.51 | 0.133 |

## MENTAL WORK EXPERIMENT No. 12.

The experiment was made with D. R. F. on the forenoon of February 15, 1905. Breakfast before the experimental period consisted of 1 shredded-wheat biscuit, a portion of cooked cereal with milk and sugar, 1 hot roll, and some dates.

In general the subject found his sojourn in the respiration chamber comfortable though novel.

The pulse rate was recorded at intervals as follows: 8.20 a. m. 76, 9.05 a. m. 83, 10 a. m. 67, 10.35 a. m. 64, 11.12 a. m. 62, and 12.10 p. m. 62.

The body temperature at 9.04 a. m. was 98° F. and at 12.04 p. m. 97.8° F.

The body weight at 8.08 a. m. was 62.268 kilograms and at 12.13 p. m. 62.113 kilograms.

In answering the questions in the examination in English literature with which the subject was engaged he wrote 2,400 words, and secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 12.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.04 to 10.34 a. m | 53.57 | 51.26 | .......... | 143.28 | .......... |
| 10.34 a. m. to 12.04 p. m | 50.27 | 43.81 | 34.15 | 131.74 | .......... |
| Total for 3 hours | 103.84 | 95.07 | .......... | 275.02 | 0.114 |

## MENTAL WORK EXPERIMENT No. 13.

The experiment was made with J. N. T. on the afternoon of February 15, 1905. Dinner, which was eaten shortly before the experimental period, consisted of a large slice of roast beef, with mashed potatoes, and stewed tomatoes, a small piece of apple pie, and a large cup of coffee.

The records kept by the subject state that when he first entered the respiration chamber he found the temperature rather high. He soon became comfortable, however, and was in no way inconvenienced, but rather considered the conditions satisfactory for taking an examination. Toward the close of the experimental period the temperature was rather cool.

The pulse rate as recorded at intervals was as follows: 1.20 p. m. 97, 2.35 p. m. 83, 3.11 p. m. 82, and 4.53 p. m. 70.

The body temperature at 2.01 p. m. was 99.4° F. and at 5.01 p. m. 98.8° F.

The body weight at 1 p. m. was 62.77 kilograms and at 5.11 p. m. 62.49 kilograms.

The subject was engaged with an examination in physics, writing 1,050 words, and secured second grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 13.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.01 to 3.31 p. m | 67.90 | 67.98 | 50.66 | 201.86 | |
| 3.31 to 5.01 p. m | 68.81 | 56.23 | 44.14 | 179.99 | |
| Total for 3 hours | 136.71 | 124.21 | 94.80 | 381.85 | 0.201 |

## MENTAL WORK EXPERIMENT No. 14.

The experiment was made with H. C. A. on the forenoon of February 16, 1905. Breakfast shortly before the experimental period consisted of a cup of coffee with a small quantity of sugar and milk and 6 buckwheat cakes with butter and sirup.

The records kept by the subject show that he was entirely comfortable in the respiration chamber and was busy during the whole period with his examination.

The pulse rate recorded at intervals was as follows: 9 a. m. 85, 11.25 a. m. 63, 11.55 a. m. 59, and 12.24 p. m. 60.

The body temperature at 9.24 a. m. was 98.9° F. and at 12.24 p. m. 97.9° F.

The body weight at 8.01 a. m. was 58.882 kilograms and at 12.32 p. m. 58.663 kilograms.

The subject was engaged with an examination in advanced analytical geometry, and secured second grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 14.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.24 to 10.54 a. m. | 46.84 | 52.46 | 36.06 | 151.07 | |
| 10.54 a. m. to 12.24 p. m. | 48.27 | 50.10 | 38.51 | 143.69 | |
| Total for 3 hours | 95.11 | 102.56 | 74.57 | 294.76 | 0.146 |

## MENTAL WORK EXPERIMENT No. 15.

The experiment was made with F. C. B. on the afternoon of February 16, 1905. Dinner shortly before the experimental period consisted of 2 small slices of roast beef, 1 potato, a slice of bread and butter, a cup of coffee with milk, and a small piece of mince pie.

The records kept by the subject show that he found the respiration chamber rather cramped quarters, though in general as satisfactory for examination purposes as the ordinary class room. In his opinion the examination called for a moderate amount of mental work. It was noticed by the observer who recorded the experimental data that the subject was rather nervous and moved his arms and hands about more than the other subjects.

The pulse rate as recorded at intervals was as follows: 1.55 p. m. 94, 2.45 p. m. 88, 3.30 p. m. 84, 4.30 p. m. 83, 5.20 p. m. 79, 5.40 p. m. 83, and 5.50 p. m. 76.

The body temperature at 2.05 p. m. was 99.2° F. and at 5.53 p. m. 98.9° F.

The body weight at 12.59 p. m. was 72.745 kilograms and at 6.07 p. m. 72.46 kilograms.

The subject was engaged with an examination paper in philosophy, and secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 15.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.05 to 3.35 p. m. | 68.05 | 54.51 | 48.69 | 177.83 | |
| 3.35 to 5.53 p. m. | 102.82 | 89.10 | 85.97 | 264.69 | |
| Total for 3 hours 48 minutes | 170.87 | 143.61 | 134.66 | 442.52 | 0.211 |

### MENTAL WORK EXPERIMENT No. 16.

The experiment was made with G. E. H. on the forenoon of February 17, 1905. Breakfast before the experimental period consisted of a dish of rolled oats with milk and part of a muffin.

The record kept by the subject shows that he had a slight headache, but this he feels sure was in no way caused by his sojourn in the respiration chamber, as otherwise he felt entirely comfortable.

The pulse rate as recorded was as follows: 9.05 a. m. 65, 10 a. m. 73, 11 a. m. 70, and 11.55 a. m. 71.

The body temperature at 9.05 a. m. was 98.4° F. and at 12.05 p. m. 98.3° F.

The body weight at 7.58 a. m. was 63.332 kilograms and at 12.14 p. m. 63.17 kilograms.

In this experiment economics was the subject of the examination paper, and second grade was secured.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 16.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.05 to 10.35 a. m. | 52.43 | 44.15 | .......... | 143.90 | .......... |
| 10.35 a. m. to 12.05 p. m. | 45.18 | 38.52 | 30.24 | 121.98 | .......... |
| Total for 3 hours | 97.61 | 82.67 | .......... | 265.88 | 0.114 |

### MENTAL WORK EXPERIMENT No. 17.

The experiment was made with N. M. P. on the afternoon of February 17, 1905. Dinner, which was eaten shortly before the experiment began, consisted of soup, roast pork with potatoes, fish croquettes, a little succotash, tomatoes, bread and butter, and apple pie.

The subject stated that he was rather nervous at first, though the feeling soon passed away. He did not have time to complete his examination paper, though he did not consider it as difficult as he had expected.

The pulse rate as recorded at intervals was as follows: 1.25 p. m. 80, 1.55 p. m. 72, 2.35 p. m. 68, 3.25 p. m. 63, 4.07 p. m. 58, and 5.05 p. m. 54.

The body temperature at 2.02 p. m. was 98.9° F. and at 5.02 p. m. 98.5° F.

The body weight at 12.50 p. m. was 70.133 kilograms and at 5.12 p. m. 69.875 kilograms.

The subject was engaged with an examination in mathematics, and secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 17.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.02 to 3.32 p. m | 66.03 | 59.23 | 49.85 | 187.50 | |
| 3.32 to 5.02 p. m | 70.42 | 55.65 | 42.73 | 178.56 | |
| Total for 3 hours | 136.45 | 114.88 | 92.58 | 366.06 | 0.177 |

## MENTAL WORK EXPERIMENT No. 18.

The experiment was made with G. W. S. on the forenoon of February 18, 1905. Breakfast, eaten shortly before the experimental period began, consisted of 2 dishes of oatmeal, 1 muffin, and a cup of coffee.

As shown by the record kept by the subject, he was a little disturbed at first by his unfamiliar surroundings, but soon became accustomed to the respiration chamber.

The pulse rate as recorded at intervals was as follows: 8.40 a. m. 70, 9.50 a. m. 85, 10.20 a. m. 88, 10.50 a. m. 81, 11.30 a. m. 76, and 11.55 a. m. 81.

The body temperature at 8.59 a. m. was 98.6° F. and at 11.59 a. m. 98.8° F.

The body weight, which was recorded as usual at the beginning and the end of the experiment, was 52.227 kilograms at 8.05 a. m. and 52.073 kilograms at 12.08 p. m.

German was the subject of the examination, and second grade was secured.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 18.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.59 to 10.29 a. m | 51.75 | 49.76 | 43.32 | 138.90 | |
| 10.29 to 11.59 a. m | 47.58 | 43.00 | 29.87 | 131.49 | |
| Total for 3 hours | 99.33 | 92.76 | 73.19 | 270.39 | 0.114 |

## MENTAL WORK EXPERIMENT No. 19.

The experiment was made with A. G. on the afternoon of February 18, 1905. Dinner, eaten shortly before the experimental period, consisted of 2 small pieces of ham, 2 potatoes, a slice of bread and butter, and a portion of rice pudding.

The record kept by the subject showed that he found his surroundings perfectly comfortable and was in no way disturbed by his sojourn in the respiration chamber.

The pulse rate recorded at intervals was as follows: 3.45 p. m. 78, 4 p. m. 84, 4.30 p. m. 83, 4.50 p. m. 81, and 5 p. m. 79.

The body temperature at 2.07 p. m. was 98.6° F. and at 5.07 p. m. 98.2° F.

The body weight at 1.05 p. m. was 61.428 kilograms and at 5.17 p. m. 61.254 kilograms.

In answering the examination questions in physics with which he was engaged the subject wrote 1,125 words, and obtained second grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 19.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.07 to 3.37 p. m. | 54.03 | 50.04 | 44.68 | 145.74 | |
| 3.37 to 5.07 p. m. | 58.23 | 50.04 | 37.72 | 149.26 | |
| Total for 3 hours | 112.26 | 100.08 | 82.40 | 295.00 | 0.124 |

## MENTAL WORK EXPERIMENT No. 20.

The experiment was made with H. L. K. on the forenoon of February 20, 1905. Breakfast, taken shortly before the experiment began, consisted of 1 banana, 4 tablespoonfuls of a dry ready-to-eat cereal, 15 teaspoonfuls of cream, a cup of coffee with 10 teaspoonfuls of cream, 1 hard-boiled egg, a biscuit, and a doughnut.

The subject stated that he was somewhat nervous in the respiration chamber, but no more so than in any place with which he was not familiar. The light was more satisfactory than he had expected. Urine was excreted, but the amount is not recorded.

The pulse rate was as follows: 8.28 a. m. 103, 8.35 a. m. 95, 8.40 a. m. 103, 8.45 a. m. 93, 8.57 a. m. 98, 9.20 a. m. 103, 9.35 a. m. 98, 9.50 a. m. 97, 10.08 a. m. 98, 10.45 a. m. 88, 10.55 a. m. 90, 11.40 a. m. 91, and 11.55 a. m. 105.

The body temperature at 8.59 a. m. was 98.9° F. and at 11.59 a. m. 98.9° F.

The body weight at 8.03 a. m. was 57.132 kilograms and at 12.09 p. m. 56.943 kilograms.

In answering the questions in the theoretical chemistry examination with which he was engaged the subject wrote 1,690 words, and secured first grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 20.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.59 to 10.29 a. m. | 54.94 | 48.05 | 33.37 | 148.30 | |
| 10.29 to 11.59 a. m. | 50.24 | 43.76 | 36.88 | 137.62 | |
| Total for 3 hours | 105.18 | 91.81 | 70.25 | 285.92 | 0.139 |

## MENTAL WORK EXPERIMENT No. 21.

The experiment was made with G. G. R. on the forenoon of February 21, 1905. Breakfast, which had been eaten shortly before the experimental period, consisted of shredded-wheat biscuit and milk, an omelet, and a cup of coffee.

The subject states that he paid little attention to his surroundings, that the light was good, and that the temperature was satisfactory, though at first a little high.

The pulse rate as recorded at intervals was as follows: 8.56 a. m. 99, 9.43 a. m. 85, 10.28 a. m. 83, and 11.20 a. m. 80.

The body temperature at 9 a. m. was 99.3° F. and at 12 noon 98.9° F.

The body weight at 8.07 a. m. was 78.494 kilograms and at 12.12 p. m. 78.253 kilograms.

Mathematics was the subject of the examination in this experiment, and first grade was secured.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 21.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9 to 10.30 a. m. | 65.67 | 55.68 | 37.13 | 181.35 | |
| 10.30 a. m. to 12 noon | 62.16 | 53.10 | 45.92 | 165.91 | |
| Total for 3 hours | 127.83 | 108.78 | 83.05 | 347.26 | 0.177 |

## MENTAL WORK EXPERIMENT No. 22.

The experiment was made with E. M. S. on the afternoon of February 21, 1905. Lunch, shortly before the experiment began, consisted of crackers and milk.

The subject stated that he was not at all nervous while in the respiration chamber. At the beginning of the period the temperature was rather high and at the close rather low. He passed 170 grams of urine.

The pulse rate record was as follows: 1.16 p. m. 93, 1.57 p. m. 92, 2.34 p. m. 98, 3.02 p. m. 95, 3.43 p. m. 89, and 4.50 p. m. 74.

The body temperature at 2 p. m. was 99.3° F. and at 5 p. m. 98.5° F.

The body weight at 12.51 p. m. was 64.211 kilograms and at 5.09 p. m. 63.995 kilograms.

The subject wrote 328 words in answering an examination in calculus, and obtained fourth grade.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 22.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2 to 3.30 p. m | 56.25 | 53.22 | 41.13 | 165.05 | |
| 3.30 to 5 p. m | 58.62 | 49.95 | 34.22 | 160.24 | |
| Total for 3 hours | 114.87 | 103.17 | 75.35 | 325.29 | 0.150 |

## SUMMARY OF RESULTS OF MENTAL WORK EXPERIMENTS.

In the following table the results obtained during the mental work tests, so far as the respiratory gases and heat production are concerned, are recorded. It will be observed that in a number of instances the determinations of oxygen are lacking. In those experiments in which it was obtained it was found that the respiratory quotient was on the average 0.913, the carbon dioxid thermal quotient 33.88, and the oxygen thermal quotient 27.5. A special discussion of these results as indexes of the general trend of normal metabolism is out of place here. The results are brought together in the table simply for the purpose of convenience.

From the tabular statements given in connection with each experiment the figures from the following table can be readily deduced, with the exception of the heat production, which is calculated from the actual amount of heat measured by the calorimeter as recorded in the tables with each experiment, a value which does not correctly represent the total heat production during the corresponding period. For example, if the temperature of the body is lowered 1° C. the body may be said to have cooled this amount, and therefore to have lost by simple radiation sufficient heat to warm the body 1° C. The specific heat of the body is commonly taken as 0.83, and hence a man weighing 60 kilograms would lose nearly 50 calories of heat if the body temperature became lowered 1°. Furthermore, if the body loses weight there is heat lost corresponding to the cooling of the weight of body material from the temperature of the body to that of the calorimeter and a correction is here necessary.

The details of this method of computation have been published in an earlier bulletin[a] of this series.

The table summarizing the results of the mental work tests follows.

[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 175.

*Summary of results of mental work experiments Nos. 1–22.*

| No. | Subject. | Body weight. | Duration of experiment. | Carbon dioxid eliminated. (a) Weight. | Carbon dioxid eliminated. (b) Volume, $a \times 0.5091$. | Oxygen consumed. (c) Weight. | Oxygen consumed. (d) Volume, $c \times 0.7$. | (e) Respiratory quotient, $b \div d$. | (f) Total water vaporized. | (g) Total heat produced. | (h) Carbon dioxid thermal quotient, $100a \div g$. | (i) Oxygen thermal quotient, $100c \div g$. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Kilograms.* | | *Grams.* | *Liters.* | *Grams.* | *Liters.* | | *Grams.* | *Calories.* | *Grams.* | *Grams.* |
| 1 | J. A. R | 59.264 | 8.59 to 11.59 a. m | 101.13 | 51.49 | 77.04 | 53.93 | 0.955 | 100.56 | 266.16 | 38.00 | 28.95 |
| 2 | H. D. A | 65.107 | 2.03 to 5.03 p. m | 94.00 | 47.86 | | | | 133.50 | 327.80 | 28.68 | |
| 3 | H. G | 49.172 | 9.04 a. m. to 12.04 p. m | 81.94 | 41.72 | | | | 106.12 | 247.03 | 33.17 | |
| 4 | F. N. C | 57.826 | 2.05 to 5.05 p. m | 106.09 | 54.01 | 77.08 | 53.96 | 1.001 | 111.78 | 300.64 | 35.29 | 25.64 |
| 5 | J. V. C | 63.193 | 9.01 a. m. to 12.01 p. m | 101.60 | 51.73 | 88.40 | 61.88 | .836 | 131.29 | 307.20 | 33.07 | 28.78 |
| 6 | A. M., jr | 67.078 | 2.01 to 5.01 p. m | 113.94 | 58.01 | | | | 148.76 | 347.03 | 32.83 | |
| 7 | F. E. R | 51.489 | 9.01 a. m. to 12.01 p. m | 89.07 | 45.35 | 70.22 | 49.15 | .932 | 119.58 | 268.39 | 33.19 | 26.16 |
| 8 | J. W. H | 60.513 | 1.55 to 4.55 p. m | 116.87 | 59.50 | 96.70 | 67.69 | .879 | 137.59 | 326.40 | 35.81 | 29.63 |
| 9 | C. A. R | 58.204 | 9 a. m. to 12 m | 92.14 | 46.91 | | | | 112.78 | 275.82 | 33.41 | |
| 10 | G. H. H | 51.558 | 9.23 a. m. to 12.32 p. m | 98.48 | 50.14 | 77.95 | 54.57 | .919 | 104.20 | 288.44 | 34.14 | 27.02 |
| 11 | H. L. W | 51.929 | 2.02 to 5.02 p. m | 85.66 | 43.61 | 70.63 | 49.44 | .882 | 123.90 | 269.65 | 31.77 | 26.19 |
| 12 | D. R. F | 62.176 | 9.04 a. m. to 12.04 p. m | 95.07 | 48.40 | | | | 103.84 | 267.43 | 35.55 | |
| 13 | J. N. T | 62.602 | 2.01 to 5.01 p. m | 124.21 | 63.24 | 94.80 | 66.36 | .953 | 136.71 | 361.21 | 34.39 | 26.25 |
| 14 | H. C. A | 58.742 | 9.24 a. m. to 12.24 p. m | 102.56 | 52.21 | 74.57 | 52.20 | 1.000 | 95.11 | 264.99 | 38.70 | 28.14 |
| 15 | F. C. B | 72.579 | 2.05 to 5.53 p. m | 143.61 | 73.11 | 134.66 | 94.26 | .776 | 170.87 | 429.00 | 33.47 | 31.39 |
| 16 | G. E. H | 63.233 | 9.05 a. m. to 12.05 p. m | 82.67 | 42.09 | | | | 97.61 | 260.79 | 31.70 | |
| 17 | N. M. P | 69.974 | 2.02 to 5.02 p. m | 114.88 | 58.49 | 92.58 | 64.81 | .902 | 136.45 | 349.67 | 32.85 | 26.48 |
| 18 | G. W. S | 52.136 | 8.59 to 11.59 a. m | 92.76 | 47.22 | 73.19 | 51.23 | .922 | 99.33 | 273.21 | 33.95 | 26.79 |
| 19 | A. G | 61.323 | 2.07 to 5.07 p. m | 100.08 | 50.95 | 82.40 | 57.68 | .883 | 112.26 | 281.71 | 35.52 | 29.25 |
| 20 | H. L. K | 57.020 | 8.59 to 11.59 a. m | 91.81 | 46.74 | 70.25 | 49.18 | .950 | 105.18 | 283.55 | 32.38 | 24.78 |
| 21 | G. G. R | 78.354 | 9 a. m. to 12 m | 108.78 | 55.38 | 83.05 | 58.14 | .953 | 127.83 | 329.84 | 32.98 | 25.18 |
| 22 | E. M. S | 64.078 | 2 to 5 p. m | 103.17 | 52.52 | 75.35 | 52.75 | .996 | 114.87 | 298.82 | 34.53 | 25.22 |
| | Average | | | 101.84 | 51.85 | 84.20 | 58.94 | .913 | 119.55 | 301.13 | 33.88 | 27.50 |

## CONTROL EXPERIMENTS.

In order to compare the metabolism of these subjects during the mental work period with a period in which the mental activity was either at a minimum or, at least presumably, much lower than that during the experimental period with mental work, each subject was requested to enter the calorimeter for a second or control experiment, in which there was little opportunity for mental work, though the time was occupied. In order to secure uniformity in movement, a routine was followed in all the experiments. It is believed that by so doing substantially all of the grosser muscular movements were eliminated. The minor movements, such as moving the arm or hand, or the involuntary muscular movements, obviously could not be the same in both the mental work and control periods. It is believed, however, that on the average reasonable uniformity of muscular activity in both sets of experiments was secured.

To offset the muscular activity of writing, the total number of words written by the subject on the examination paper during the mental work period was counted, and he was required to write an equivalent number of words, copied in part from a formal report of no general interest and in part from a popular magazine in which more interest would naturally be aroused. The copying from the formal report occupied a portion of the time during the first experimental period and the copying from the magazine was done during the second experimental period. It was impossible under college conditions to have the control experiments follow immediately after the mental work tests, but the control tests were made as soon as possible after them.

Unfortunately, it was inexpedient to secure regularity in the food eaten prior to the control period, but the control was always so arranged as to occur at about the same hours of the day that were covered by the mental work test.

## STATISTICS OF THE CONTROL EXPERIMENTS.

In the following pages the data for the control experiments are recorded. In addition to their value for comparison with the mental work tests these experiments throw interesting light on the normal metabolism of healthy young men at rest.

### CONTROL EXPERIMENT No. 23.

The experiment was made with J. A. R. on the forenoon of February 28, 1905. Breakfast, which was eaten shortly before the experiment began, consisted of $2\frac{1}{2}$ tablespoonfuls of cereal breakfast food with milk and sugar, and a small slice of graham bread and butter.

The subject stated that he was rather uncomfortable owing to a cold, and he states that the period in the respiration chamber was rather tedious.

The pulse rate as recorded was as follows: 8.25 a. m. 86, 10.35 a. m. 77, 10.37 a. m. 75, 10.41 a. m. 82, 12 noon 65, 12.02 p. m. 68, and 12.14 p. m. 70.

The body temperature at the beginning of the experimental period, 9.15 a. m., was 98.4° F., and at the end, 12.15 p. m., it was 97.8° F.

The body weight at 8.05 a. m. was 59.018 kilograms and at 12.23 p. m. 58.85 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 23.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| .15 to 10.45 a. m | 48.57 | 44.07 | 32.20 | 154.36 | |
| 10.45 a. m. to 12.15 p. m | 42.45 | 40.44 | 30.00 | 132.98 | |
| Total for 3 hours | 91.02 | 84.51 | 62.20 | 287.34 | 0.117 |

## CONTROL EXPERIMENT No. 24.

This experiment was made with H. D. A. on the afternoon of February 28, 1905. Dinner, which was eaten shortly before the experiment, consisted of a portion of potpie equivalent to a slice of beef and 2 slices of bread, a small potato, a portion of stewed tomatoes, and an orange of medium size.

According to the subject's notes, he found the air in the respiration chamber rather chilly. The material was easy to copy, the report being more interesting than the other article. The copy was finished at 4 p. m.

The pulse rate taken at intervals was as follows: 2 p. m. 82, 2.30 p. m. 73, 3 p. m. 71, 3.32 p. m. 69, 4. p. m. 65, 4.30 p. m. 67, 4.58 p. m. 66, 5.28 p. m. 63, and 6 p. m. 67.

The body temperature at 2.03 p. m. was 98.5° F. and at 5.03 p. m. 98° F.

The body weight at 1.24 p. m. was 67.237 kilograms and at 5.13 p. m. 65.01 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 24.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram* |
| 2.03 to 3.33 p. m | 61.92 | 58.03 | 55.68 | 175.74 | |
| 3.33 to 5.03 p. m | 68.99 | 53.96 | 43.63 | 165.28 | |
| Total for 3 hours | 130.91 | 111.99 | 99.31 | 341.02 | 0.176 |

## CONTROL EXPERIMENT No. 25.

This experiment was made with H. G. on the forenoon of February 24, 1905. Breakfast eaten before the experiment began consisted of a shredded-wheat biscuit, a glass of milk, a tablespoonful of sugar, a biscuit, and a cup of coffee.

According to the subject's notes, the air in the respiration chamber seemed very warm for a time and he was drowsy. He found the copying very easy, but in general it was not interesting. The copy was finished at 11.28 a. m.

The pulse rate as recorded was as follows: 8.07 a. m. 71, 8.40 a. m. 72, 9.15 a. m. 69, 9.45 a. m. 66, 10.15 a. m. 73, 10.45 a. m. 71, 11.15 a. m. 62, and 11.50 a. m. 69.

The body temperature at 9.15 a. m. was 98.1° F. and at 12.15 p. m. 98.2° F.

The body weight at 8.02 a. m. was 49.212 kilograms and at 12.23 p. m. 49.053 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 25.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.15 to 10.45 a. m. | 43.15 | 45.09 | .......... | 116.47 | .......... |
| 10.45 a. m. to 12.15 p. m. | 45.88 | 38.52 | 29.83 | 116.13 | .......... |
| Total for 3 hours | 89.03 | 83.61 | .......... | 232.60 | 0.110 |

## CONTROL EXPERIMENT No. 26.

This experiment was made with F. N. C. on the afternoon of February 25, 1905. The dinner the subject ate shortly before the experiment began consisted of a little potato and corned beef, some corn fritters, and a piece of jelly cake.

According to the subject's notes, he found the respiration chamber comfortable and the air good. He felt drowsy part of the time and the copying became monotonous, his hand and arm being tired.

The pulse rate as recorded was as follows: 2.03 p. m. 72, 2.30 p. m. 72, 3 p. m. 64, 3.30 p. m. 70, 4.15 p. m. 70, 4.30 p. m. 62, and 4.55 p. m. 64.

The body temperature at 2 p. m. was 97.8° F. and at 5 p. m. 97.5° F.

The body weight at 1.20 p. m. was 57.462 kilograms and at 5.10 p. m. 57.316 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 26.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2 to 3.30 p. m. | 48.60 | 48.27 | 42.67 | 158.17 | ........... |
| 3.30 to 5 p. m. | 47.65 | 48.84 | .......... | 147.22 | ........... |
| Total for 3 hours | 96.25 | 97.11 | .......... | 305.39 | 0.115 |

## CONTROL EXPERIMENT No. 27.

This experiment was made with J. V. C. on the forenoon of March 21, 1905. Breakfast before the experiment began consisted of 3 pancakes with butter and sirup and a cup of coffee with sugar and milk.

According to the subject's notes, he drank, shortly after the experiment began, 106 cubic centimeters water and passed 380 cubic centimeters urine. He felt perfectly comfortable during the entire experimental period, but found the report which he copied rather tedious. The copy was finished at 11.40 a. m.

The pulse rate as recorded was as follows: 8.33 a. m. 74, 8.55 a. m. 74, 9.25 a. m. 75, 9.55 a. m. 67, 10.25 a. m. 66, 10.55 a. m. 60, 11.25 a. m. 65, and 11.40 a. m. 65.

The body temperature at 8.48 a. m. was 98° F. and at 11.48 a. m. 97.9° F.

The body weight at 8.01 a. m. was 63.144 kilograms and at 11.57 946 kilograms.

*rbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 27.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimi-nated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.48 to 10.18 a. m. | 66.86 | 52.81 | 42.38 | 165.17 | ........... |
| 10.18 to 11.48 a. m. | 63.24 | 44.82 | 31.62 | 154.52 | ........... |
| Total for 3 hours | 130.10 | 97.63 | 74.00 | 319.69 | 0.151 |

## CONTROL EXPERIMENT No. 28.

This experiment was made with A. M. on the afternoon of March 1, 1905. Dinner, which was eaten shortly before the experiment began, consisted of a plate of soup, a plate of baked beans, with fried potatoes, 4 slices of toast, a glass of milk, a cup of tea, and an apple.

According to the subject's notes, he was perfectly comfortable in he respiration chamber, though sleepy in the early part of the ex- rimental period. He found the copying not at all tedious, though

it was done rather mechanically, his mind being on something else while engaged with it.

The pulse rate as recorded was as follows: 2 p. m. 81, 2.45 p. m. 76, 3.30 p. m. 73, and 4.15 p. m. 70.

The body temperature at 1.48 p. m. was 98.8° F. and at 4.48 p. m. 98.3° F.

The body weight at 1.14 p. m. was 66.638 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 28.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 1.48 to 3.18 p. m. | 53.59 | 51.50 | 40.69 | 160.24 | |
| 3.18 to 4.48 p. m. | 59.37 | 53.64 | 41.35 | 151.53 | |
| Total for 3 hours | 112.96 | 105.14 | 82.04 | 311.77 | 0.145 |

## CONTROL EXPERIMENT No. 29.

This experiment was made with F. E. R. on the forenoon of February 25, 1905. Breakfast taken before the experiment began consisted of a small dish of oatmeal with milk and sugar and a cup of coffee with milk and sugar.

The subject stated in his notes that during the early part of the experimental period he felt decidedly warm and that in general the copying was uninteresting and tiresome. He finished writing at 11.20 a. m.

The pulse rate as recorded was as follows: 8.12 a. m. 99, 9.20 a. m. 94, 9.39 a. m. 97, 10.02 a. m. 86, 10.35 a. m. 82, 11 a. m. 88, 11.23 a. m. 88, and 12.03 p. m. 90.

The body temperature at 9 a. m. was 99.3° F. and at 12 noon 99.2° F.

The body weight at 8.02 a. m. was 52.981 kilograms and at 12.09 p. m. 52.747 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 29.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9 to 10.30 a.m. | 68.16 | 43.64 | 34.42 | 163.65 | |
| 10.30 a. m. to 12 noon | 56.37 | 42.09 | 30.65 | 137.59 | |
| Total for 3 hours | 124.53 | 85.73 | 65.07 | 301.24 | 0.170 |

## CONTROL EXPERIMENT No. 30.

This experiment was made with J. W. H. on the afternoon of March 23, 1905. Lunch, which was eaten shortly before the experiment began, consisted of 2 glasses of milk, 2 slices of bread and butter, 4 slices of cold corned beef with horseradish, a sugar cooky, and a piece of cocoanut cake.

In general the subject states that he felt much the same as in the mental work experiment (see p. 67), but found the copying rather dull and monotonous.

The pulse rate as recorded was as follows: 1.50 p. m. 71, 2.35 p. m. 69, 3.30 p. m. 70, and 4.30 p. m. 69.

The body temperature at 1.40 p. m. was 98.5° F. and at 4.40 p. m. 98.3° F.

The body weight at 1.05 p. m. was 61.26 kilograms and at 4.40 p. m. 61.063 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 30.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 1.40 to 3.10 p. m. | 69.15 | 61.88 | 51.92 | 170.42 | ............ |
| 3.10 to 4.40 p. m. | 73.34 | 58.51 | 45.21 | 174.75 | ............ |
| Total for 3 hours | 142.49 | 120.39 | 97.13 | 345.17 | 0.165 |

## CONTROL EXPERIMENT No. 31.

This experiment was made with C. A. R. on the forenoon of March 18, 1905. The breakfast which the subject ate before the experiment consisted of 2 dishes of oatmeal, a glass of milk, and some fried potatoes.

According to the subject's notes, he found the copying monotonous, though the magazine was more interesting than the report, and he found it difficult to keep from being interested in it.

The pulse rate as recorded was as follows: 9 a. m. 108, 9.30 a. m. 100, 10 a. m. 95, 10.30 a. m. 87, 11 a. m. 89, 11.30 a. m. 77, 12 noon 78, and 12.30 p. m. 85.

The body temperature at 8.57 a. m. was 98.3° F. and at 11.57 a. m. 98° F

The body weight at 8.16 a. m. was 59.73 kilograms and at 12.08 p. m. 59.544 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 31.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.57 to 10.27 a. m. | 60.03 | 55.05 | 41.94 | 160.91 | ........... |
| 10.27 to 11.57 a. m. | 58.45 | 46.93 | 36.18 | 141.53 | ........... |
| Total for 3 hours | 118.48 | 101.98 | 78.12 | 302.44 | 0.144 |

## CONTROL EXPERIMENT No. 32.

This experiment was made with G. H. H. on the forenoon of March 23, 1905. Breakfast, eaten before the experiment began, consisted of a saucer of dry cereal with sugar and milk, 2 biscuits, and a glass of milk.

The subject states that he did not feel fatigued during the experimental period. In his opinion the copying required some mental work, and he felt that mere scribbling would have been more nearly equivalent to the mechanical effort of the mental work experiment (see p. 68).

The pulse rate as recorded was as follows: 9.05 a. m. 97, 9.34 a. m. 90, 10.09 a. m. 88, 10.45 a. m. 85, 11.15 a. m. 91, and 11.45 a. m. 85.

The body temperature at 8.47 a. m. was 98.5° F. and at 11.56 a. m. 98.6° F.

The body weight at 8.23 a. m. was 51.656 kilograms and at 12.37 p. m. 51.484 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 32.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.47 to 9.56 a. m. | 42.44 | 39.45 | 31.11 | 103.86 | ........... |
| 9.56 to 11.56 a. m. | 72.91 | 59.99 | 59.10 | 176.02 | ........... |
| Total for 3 hours 9 minutes | 115.35 | 99.44 | 90.21 | 279.88 | 0.125 |

## CONTROL EXPERIMENT No. 33.

This experiment was made with H. L. W. on the afternoon of February 24, 1905. Dinner, eaten before the experiment began, consisted of a small portion of roast beef, a small potato with gravy, a small dish of green peas, a biscuit, a portion of bread pudding, and a glass of milk.

According to the subject's notes, he began writing at 2.24 p. m. and at 4.04 had finished ten pages. This he reviewed and then

wrote two pages additional. He found the light rather troublesome. He was somewhat sleepy during the experimental period, as he had slept only eight hours during the preceding sixty hours. He found that copying the magazine article required less effort than copying the report.

The pulse rate as recorded was as follows: 2.05 p. m. 86, 2.30 p. m. 80, 3 p. m. 80, 3.35 p. m. 74, 4 p. m. 68, 4.35 p. m. 69, and 5.05 p. m. 69.

The body temperature at 2.22 p. m. was 99° F. and at 5.22 p. m. 98.3° F.

The body weight at 1.20 p. m. was 51.623 kilograms and at 5.32 p. m. 51.419 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 33.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.22 to 3.52 p. m. | 60.42 | 48.92 | 40.45 | 155.19 | .......... |
| 3.52 to 5.22 p. m. | 60.58 | 40.59 | 33.84 | 148.58 | .......... |
| Total for 3 hours | 121.00 | 89.51 | 74.29 | 303.77 | 0.146 |

## CONTROL EXPERIMENT No. 34.

This experiment was made with D. R. F. on the forenoon of March 2, 1905. The subject had eaten for breakfast oatmeal with milk, soda crackers, a hot biscuit, and an apple.

According to his notes, he found the light satisfactory and was in no way inconvenienced by his stay in the respiration chamber. The material copied was not very interesting and no appreciable difference was noted in this respect between the report and the magazine article.

The pulse rate as recorded was as follows: 8.24 a. m. 83, 9 a. m. 87, 9.45 a. m. 80, 10.15 a. m. 72, 11 a. m. 70, and 11.30 a. m. 68.

The body temperature at 8.46 a. m. was 98° F. and at 11.46 a. m. 97.7° F.

The body weight at 8.14 a. m. was 62.583 kilograms and at 11.55 a. m. 62.429 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 34.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.46 to 10.16 a. m. | 46.65 | 59.56 | 43.32 | 144.89 | .......... |
| 10.16 to 11.46 a. m. | 44.43 | 45.24 | 34.95 | 134.30 | .......... |
| Total for 3 hours | 91.08 | 104.80 | 78.27 | 279.19 | 0.126 |

## CONTROL EXPERIMENT No. 35.

This experiment was made with J. N. T. on the afternoon of March 2, 1905. The subject had eaten for dinner shortly before the experiment a pork chop, 2 boiled potatoes, a dish of cooked onions, 2 slices of bread, and a piece of prune pie.

According to the subject's notes, he had a slight headache for part of the period and thought that the air in the respiration chamber was somewhat closer than in the mental work experiment (see p. 70). He found the copying uninteresting.

The pulse as taken at intervals was as follows: 1.45 p. m. 78, 2.30 p. m. 93, 3.30 p. m. 73, 4.30 p. m. 63, and 5 p. m. 61.

The body temperature at 2.16 p. m. was 98.7° F. and at 5.16 p. m. 97.7° F.

The body weight at 1.07 p. m. was 63.596 kilograms and at 5.25 p. m. 63.406 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 35.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.16 to 3.46 p. m. | 49.14 | 56.02 | 41.76 | 180.69 | |
| 3.46 to 5.16 p. m. | 56.77 | 52.66 | 41.11 | 164.68 | |
| Total for 3 hours | 105.91 | 108.68 | 82.87 | 345.37 | 0.132 |

## CONTROL EXPERIMENT No. 36.

This experiment was made with H. C. A. on the forenoon of February 27, 1905. Breakfast, which was eaten shortly before the experiment began, consisted of a cup of coffee with sugar and milk, one-half glass of milk, 3 or 4 crackers, and 6 graham biscuits with butter.

According to the subject's notes, he was not especially sleepy during the experimental period and was somewhat interested in the report and the magazine article which he copied, but more particularly in the latter.

The pulse rate as recorded at intervals was as follows: 9 a. m. 69, 9.51 a. m. 58, 10.28 a. m. 54, 10.58 a. m. 54, and 11.36 a. m. 48.

The body temperature at 8.52 a. m. was 97.8° F. and at 11.52 a. m. 97.3° F.

The body weight at 8.10 a. m. was 59.019 kilograms and at 12.01 p. m. 58.883 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 36.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimina-ted. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.52 to 10.22 a. m | 42.80 | 48.55 | 36.79 | 162.41 | |
| 10.22 to 11.52 a. m | 39.66 | 43.04 | 35.88 | 135.80 | |
| Total for 3 hours | 82.46 | 91.59 | 72.67 | 298.21 | 0.106 |

## CONTROL EXPERIMENT No. 37.

This experiment was made with F. C. B. on the afternoon of March 22, 1905. Dinner eaten not long before the experiment began consisted of 2 slices of roast beef, 2 small potatoes, a small dish of string beans, a small piece of lemon pie, an orange, and a cup of coffee with milk.

The subject states in his notes that he found the light good and was comfortable, the air in the respiration chamber being warm at first and cold later on. He preferred the copying to the mental work of the earlier experiment of which he was the subject. (See p. 71).

The pulse rate as recorded was as follows: 1.55 p. m. 88, 2.25 p. m. 87, 3.10 p. m. 81, 3.55 p. m. 79, 4.55 p. m. 77, 5.40 p. m. 76, and 6.05 p. m. 74.

The body temperature at 2.21 p. m. was 98.5° F. and at 6.09 p.m. 97.8° F.

The body weight at 1.20 p. m. was 74.728 kilograms and at 6.17 p. m. 74.45 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 37.*

| Time. | Water vapo-rized. | Carbon dioxid elimi-nated. | Oxygen absorbed. | Heat elimina-ted. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.21 to 3.51 p. m | 69.14 | 56.50 | 40.68 | 186.82 | |
| 3.51 to 6.09 p. m | 112.89 | 76.87 | 66.08 | 249.89 | |
| Total for 3 hours and 48 minutes | 182.03 | 133.37 | 106.76 | 436.71 | 0.214 |

## CONTROL EXPERIMENT No. 38.

This experiment was made with G. E. H. on the forenoon of March 22, 1905. The subject had eaten for breakfast a dish of rolled oats with milk and a muffin.

In his notes the subject states that he felt sleepy during the experimental period, particularly while copying the report. When working with the magazine he found it somewhat difficult to refrain from

reading the various articles, but did not do any extended or connected reading.

The pulse rate as recorded was as follows: 9.10 a. m. 61, 10 a. m. 58, 10.30 a. m. 60, 11.30 a. m. 56, and 11.56 a. m. 60.

The body temperature at 9.07 a. m. was 97.5° F. and at 12.07 p. m. 97.4° F.

The body weight at 8.03 a. m. was 63.146 kilograms and at 12.18 p. m. 62.994 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 38.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.07 to 10.37 a. m. | 53.14 | 41.49 | 32.01 | 132.89 | ........... |
| 10.37 a. m. to 12.07 p. m. | 50.39 | 36.77 | 29.81 | 119.68 | ........... |
| Total for 3 hours | 103.53 | 78.26 | 61.82 | 252.57 | 0.107 |

## CONTROL EXPERIMENT No. 39.

This experiment was made with N. M. P. on the afternoon of February 27, 1905. Lunch eaten a short time before the experiment began consisted of 4 chicken sandwiches, 2 cups of cocoa, and an orange.

In his notes the subject states that he found the copying tiresome and became sleepy. He required about five minutes to write a page.

The pulse rate as recorded was as follows: 1.58 p. m. 73, 2.35 p. m. 73, 3.15 p. m. 64, 3.38 p. m. 62, 4.57 p. m. 59, and 5.55 p. m. 56.

The body temperature at 2 p. m. was 98.7° F. and at 5 p. m. 98.4° F.

The body weight at 2 p. m. was 69.805 kilograms and at 5.10 p. m. 69.668 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 39.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. |
|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* |
| 2 to 3.30 p. m. | 50.86 | 54.02 | 43.85 | 180.04 |
| 3.30 to 5 p. m. | 56.76 | 58.56 | 46.28 | 174.83 |
| Total for 3 hours | 107.62 | 112.58 | 90.13 | 354.87 |

## CONTROL EXPERIMENT No. 40.

This experiment was made with G. W. S. on the forenoon of March 25, 1905. Breakfast eaten before the experiment began consisted of 2 dishes of oatmeal and 3 muffins.

The subject states that he felt indolent throughout the whole experimental period, and took a longer time to write the 19½ pages, which he completed, than he did for the examination with which he was engaged in the earlier experiment (see p. 73).

The pulse rate as recorded was as follows: 8.50 a. m. 93, 9.15 a. m. 88, 9.45 a. m. 93, 10.15 a. m. 81, 10.45 a. m. 79, 11.15 a. m. 79, 11.45 a. m. 80, 12 noon 79, and 12.30 p. m. 71.

The body temperature at 9.10 a. m. was 97.4° F. and at 12.10 p. m. 97.6° F.

The body weight at 8.09 a. m. was 50.771 kilograms and at 12.19 p. m. 50.651 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 40.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 9.10 to 10.40 a. m. | 57.22 | 42.73 | 38.94 | 124.88 | |
| 10.40 a. m. to 12.10 p. m. | 56.34 | 40.02 | 26.93 | 125.39 | |
| Total for 3 hours | 113.56 | 82.75 | 65.87 | 250.27 | 0.087 |

### CONTROL EXPERIMENT No. 41.

This experiment was made with A. G. on the afternoon of March 18, 1905. Dinner, which was eaten before the experiment, consisted of roast pork with potatoes, 3 slices of bread and butter, a piece of lemon pie, and a dish of prunes.

In his notes the subject states that he felt warm in the early part of the experimental period and that the time passed very slowly. He was rather more interested in the magazine article than in the report which he copied.

The pulse rate as recorded was as follows: 2.04 p. m. 92, 2.30 p. m. 84, 3.07 p. m. 84, 3.20 p. m. 72, 3.50 p. m. 72, 4.30 p. m. 66, and 4.55 p. m. 70.

The body temperature at 2 p. m. was 97.9° F. and at 5 p. m. 97.7° F.

The body weight at 1.12 p. m. was 63.313 kilograms and at 5.11 p. m. 63.102 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 41.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2 to 3.30 p. m. | 65.53 | 58.27 | 44.20 | 173.00 | |
| 3.30 to 5 p. m. | 65.29 | 51.87 | 42.59 | 153.56 | |
| Total for 3 hours | 130.82 | 110.14 | 86.79 | 326.56 | 0.159 |

## CONTROL EXPERIMENT No. 42.

This experiment was made with H. L. K. on the forenoon of March 1, 1905. The subject had eaten for breakfast that morning a banana, 4 tablespoonfuls of dry cereal with 15 teaspoonfuls of cream, a cup of coffee with 10 teaspoonfuls of cream, and 2 teaspoonfuls of sugar, an egg, a biscuit, and a doughnut, or practically the same breakfast as in the earlier experiment of which he was the subject (see p. 74).

In his notes he states that he was not at all excited, though he had a slight headache. He found it somewhat difficult not to become interested in the report which he copied. The copying was completed at 11.35 and he then spent twenty minutes in glancing over what he had written.

The pulse rate as recorded was as follows: 8.15 a. m. 95, 8.28 a. m. 90, 8.35 a. m. 93, 8.45 a. m. 97, 8.57 a. m. 91, 9.20 a. m. 82, 9.35 a. m. 84, 9.50 a. m. 71, 10.15 a. m. 72, 10.45 a. m. 75, 11.15 a. m. 70, and 11.45 a. m. 76.

The body temperature at 8.54 a. m. was 98.1° F. and at 11.54 a. m. 98.5° F.

The body weight at 8 a. m. was 57.165 kilograms and at 12.04 p. m. 57.019 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 42.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.54 to 10.24 a. m. | 48.85 | 45.47 | 37.31 | 143.84 | |
| 10.24 to 11.54 a. m. | 43.85 | 42.28 | 34.50 | 128.04 | |
| Total for 3 hours | 92.70 | 87.75 | 71.81 | 271.88 | 0.108 |

## CONTROL EXPERIMENT No. 43.

This experiment was made with G. G. R. on the forenoon of March 20, 1905. Breakfast that morning consisted of 2 dishes of a cooked wheat breakfast food with milk, milk toast, and coffee.

The subject states that he found the experimental period somewhat tedious and the report which he copied uninteresting. The magazine article was a little more interesting. The temperature of the respiration chamber was satisfactory.

The pulse rate as taken at intervals was as follows: 9 a. m. 76, 9.45 a. m. 70, 10.30 a. m. 70, 11.15 a. m. 68, and 12 noon 69.

The body temperature at 8.53 a. m. was 98.6° F. and at 11.53 a. m. 98.5° F.

The body weight at 8.01 a. m. was 77.272 kilograms and at 12.06 p. m. 77.03 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 43.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 8.53 to 10.23 a. m. | 66.45 | 61.11 | ........ | 175.33 | ........ |
| 10.23 to 11.53 a. m. | 66.18 | 55.03 | ........ | 164.15 | ........ |
| Total for 3 hours | 132.63 | 116.14 | ........ | 339.48 | 0.178 |

## CONTROL EXPERIMENT No. 44.

This experiment was made with E. M. S. on the afternoon of March 21, 1905. The subject ate no dinner with the exception of about one-fourth of an orange, but had eaten for breakfast about five hours before the experiment began a banana, a portion of dry cereal with 3 teaspoonfuls of sugar and one-fourth pint of cream, a few raisins, a fig, about one-half pint of milk, and a slice of whole-wheat bread with 5 or 6 grams of peanut butter.

According to the subject's notes, the air in the respiration chamber was rather warm at first, though later on it became rather cool. Copying the magazine article he considered more interesting than the report. Toward the end of the experimental period he states that he was rather hungry.

The pulse rate as recorded at intervals was as follows: 2.30 p. m. 80, 2.50 p. m. 78, 3.20 p. m. 74, 3.43 p. m. 72, 4.14 p. m. 76, 4.50 p. m. 75, and 5.12 p. m. 74.

The body temperature at 2.16 p. m. was 98.4° F. and at 5.16 p. m. 98.2° F.

The body weight at 1.33 p. m. was 64.446 kilograms and at 5.26 p. m. 64.272 kilograms.

*Carbon dioxid, water vapor, and heat eliminated and oxygen absorbed, experiment No. 44.*

| Time. | Water vaporized. | Carbon dioxid eliminated. | Oxygen absorbed. | Heat eliminated. | Loss in body weight. |
|---|---|---|---|---|---|
| | *Grams.* | *Grams.* | *Grams.* | *Calories.* | *Kilogram.* |
| 2.16 to 3.46 p. m. | 63.84 | 48.59 | 40.21 | 178.16 | ........ |
| 3.46 to 5.16 p. m. | 60.45 | 42.99 | 32.67 | 150.41 | ........ |
| Total for 3 hours | 124.29 | 91.58 | 72.88 | 328.57 | 0.135 |

## SUMMARY OF RESULTS OF CONTROL EXPERIMENTS.

The carbon dioxid and water eliminated, the oxygen consumption, and the heat production in the control experiments are summarized in the following table.

*Summary of results of control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Average body weight. | Duration of experiment. | Carbon dioxid eliminated. (a) Weight. | Carbon dioxid eliminated. (b) Volume, $a \times 0.5091$. | Oxygen consumed. (c) Weight. | Oxygen consumed. (d) Volume, $c \times 0.7$. | (e) Respiratory quotient, $b \div d$. | (f) Total water vaporized. | (g) Total heat produced.[a] | (h) Carbon dioxid thermal quotient, $100\ a \div g$. | (i) Oxygen thermal quotient, $100\ c \div g$. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Kilograms.* | | *Grams.* | *Liters.* | *Grams.* | *Liters.* | | *Grams.* | *Calories.* | *Grams.* | *Grams.* |
| 1 | 23 | J. A. R. | 58.914 | 9.15 a. m. to 12.15 p.m. | 84.51 | 43.02 | 62.20 | 43.54 | 0.988 | 91.02 | 269.15 | 31.40 | 23.11 |
| 2 | 24 | H. D. A. | 67.111 | 2.03 to 5.03 p. m. | 111.99 | 57.01 | 99.31 | 69.52 | .820 | 130.91 | 322.97 | 34.68 | 30.75 |
| 3 | 25 | H. G. | 49.113 | 9.15 a. m. to 12.15 p. m. | 83.61 | 42.57 | ........ | ........ | ........ | 89.03 | 233.22 | 35.85 | ........ |
| 4 | 26 | F. N. C. | 57.380 | 2 to 5 p. m. | 97.11 | 49.44 | ........ | ........ | ........ | 96.25 | 295.41 | 32.87 | ........ |
| 5 | 27 | J. V. C. | 63.030 | 8.48 to 11.48 a. m. | 97.63 | 49.70 | 74.00 | 51.80 | .959 | 130.10 | 318.36 | 30.67 | 23.24 |
| 6 | 28 | A. M., jr. | 66.539 | 1.48 to 4.48 p. m. | 105.14 | 53.53 | 82.04 | 57.43 | .932 | 112.96 | 293.83 | 35.78 | 27.92 |
| 7 | 29 | F. E. R. | 52.841 | 9 a. m. to 12 m. | 85.73 | 43.65 | 65.07 | 45.55 | .958 | 124.53 | 295.59 | 29.00 | 22.01 |
| 8 | 30 | J. W. H. | 61.146 | 1.40 to 4.40 p. m. | 120.39 | 61.29 | 97.13 | 67.99 | .901 | 142.49 | 340.06 | 35.40 | 28.56 |
| 9 | 31 | C. A. R. | 59.625 | 8.57 to 11.57 a. m. | 101.98 | 51.92 | 78.12 | 54.68 | .949 | 118.48 | 292.07 | 34.92 | 26.75 |
| 10 | 32 | G. H. H. | 51.596 | 8.47 to 11.56 a. m. | 99.44 | 50.62 | 90.21 | 63.15 | .802 | 115.35 | 280.29 | 35.48 | 32.18 |
| 11 | 33 | H. L. W. | 51.500 | 2.22 to 5.22 p. m. | 89.51 | 45.57 | 74.29 | 52.00 | .876 | 121.00 | 284.60 | 31.45 | 26.10 |
| 12 | 34 | D. R. F. | 62.498 | 8.46 to 11.46 a. m. | 104.80 | 53.35 | 78.27 | 54.79 | .974 | 91.08 | 268.27 | 39.07 | 29.18 |
| 13 | 35 | J. N. T. | 63.479 | 2.16 to 5.16 p. m. | 108.68 | 55.33 | 82.87 | 58.01 | .954 | 105.91 | 313.68 | 34.65 | 26.42 |
| 14 | 36 | H. C. A. | 58.941 | 8.52 to 11.52 a. m. | 91.59 | 46.63 | 72.67 | 50.87 | .917 | 82.46 | 282.77 | 32.39 | 25.70 |
| 15 | 37 | F. C. B. | 74.564 | 2.21 to 6.09 p. m. | 133.37 | 67.90 | 106.76 | 74.73 | .909 | 182.03 | 409.66 | 32.56 | 26.06 |
| 16 | 38 | G. E. H. | 63.055 | 9.07 a. m. to 12.07 p. m. | 78.26 | 39.84 | 61.82 | 43.27 | .921 | 103.53 | 247.66 | 31.60 | 24.96 |
| 17 | 39 | N. M. P. | 69.740 | 2 to 5 p. m. | 112.58 | 57.31 | 90.13 | 63.09 | .908 | 107.62 | 343.19 | 32.80 | 26.26 |
| 18 | 40 | G. W. S. | 50.699 | 9.10 a. m. to 12.10 p. m. | 82.75 | 42.13 | 65.87 | 46.11 | .914 | 113.56 | 253.48 | 32.65 | 25.99 |
| 19 | 41 | A. G. | 63.192 | 2 to 5 p.m. | 110.14 | 56.07 | 86.79 | 60.75 | .923 | 130.82 | 318.12 | 34.62 | 27.28 |
| 20 | 42 | H. L. K. | 57.079 | 8.54 to 11.54 a. m. | 87.75 | 44.67 | 71.81 | 50.27 | .889 | 92.70 | 280.43 | 31.29 | 25.61 |
| 21 | 43 | G. G. R. | 77.132 | 8.53 to 11.53 a. m. | 116.14 | 59.13 | ........ | ........ | ........ | 132.63 | 332.55 | 34.92 | ........ |
| 22 | 44 | E. M. S. | 64.347 | 2.16 to 5.16 p.m. | 91.58 | 46.62 | 72.88 | 51.02 | .914 | 124.29 | 320.45 | 28.58 | 22.74 |
| | | Average | ........ | ........ | 99.76 | 50.79 | 79.48 | 55.63 | .915 | 115.40 | 299.81 | 33.30 | 25.80 |

[a] For discussion of heat production as compared with heat elimination, see page 56.

## DISCUSSION OF RESULTS OF MENTAL WORK AND CONTROL EXPERIMENTS.

In discussing the mental work experiments and the control tests it seems best to consider specifically the pulse rate, the body temperature, the carbon dioxid and water outgo, the heat production, and the oxygen consumption of the subject in the two periods rather than to attempt on the basis of the available experimental data a discussion of general metabolism.

### BODY TEMPERATURE.

The body temperature at the beginning and end of the experimental period in both the mental work and control experiments and the average temperature at the beginning and end of each experiment are recorded in the table below. It will be remembered that these temperatures were taken in the mouth, the thermometer being inserted by the subject himself, and although it was retained in the mouth for five minutes and all precautions were taken to secure as satisfactory a temperature measurement as possible, nevertheless it is only with the average results that any satisfactory comparison can be made.

*Comparison of body temperature, mental work and control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Mental work experiments. Beginning. | Mental work experiments. End. | Control experiments. Beginning. | Control experiments. End. |
|---|---|---|---|---|---|---|
| | | | °F. | °F. | °F. | °F. |
| 1 | 23 | J. A. R. | 98.5 | 97.5 | 98.4 | 97.8 |
| 2 | 24 | H. D. A. | 98.7 | 98.3 | 98.5 | 98.0 |
| 3 | 25 | H. G. | 99.0 | 98.2 | 98.1 | 98.2 |
| 4 | 26 | F. N. C. | 98.1 | 97.8 | 97.8 | 97.5 |
| 5 | 27 | J. V. C. | 98.3 | 98.3 | 98.0 | 97.9 |
| 6 | 28 | A. M., jr. | 99.2 | 98.9 | 98.8 | 98.3 |
| 7 | 29 | F. E. R. | 99.7 | 99.4 | 99.3 | 99.2 |
| 8 | 30 | J. W. H. | 98.9 | 98.0 | 98.5 | 98.3 |
| 9 | 31 | C. A. R. | 99.2 | 98.0 | 98.3 | 98.0 |
| 10 | 32 | G. H. H. | ...... | ...... | [a]98.5 | [a]98.6 |
| 11 | 33 | H. L. W. | 99.5 | 98.6 | 99.0 | 98.3 |
| 12 | 34 | D. R. F. | 98.0 | 97.8 | 98.0 | 97.7 |
| 13 | 35 | J. N. T. | 99.4 | 98.8 | 98.7 | 97.7 |
| 14 | 36 | H. C. A. | 98.9 | 97.9 | 97.8 | 97.3 |
| 15 | 37 | F. C. B. | 99.2 | 98.9 | 98.5 | 97.8 |
| 16 | 38 | G. E. H. | 98.4 | 98.3 | 97.5 | 97.4 |
| 17 | 39 | N. M. P. | 98.9 | 98.5 | 98.7 | 98.4 |
| 18 | 40 | G. W. S. | 98.6 | 98.8 | 97.4 | 97.6 |
| 19 | 41 | A. G. | 98.6 | 98.2 | 97.9 | 97.7 |
| 20 | 42 | H. L. K. | 98.9 | 98.9 | 98.1 | 98.5 |
| 21 | 43 | G. G. R. | 99.3 | 98.9 | 98.6 | 98.5 |
| 22 | 44 | E. M. S. | 99.3 | 98.5 | 98.4 | 98.2 |
| | | Average. | 98.9 | 98.4 | 98.3 | 98.0 |

[a] Not included in the average.

The results recorded above show that the average sublingual temperature of the men just before beginning the examination was 98.9° F. At the end of the three-hour examination period the average temperature was 98.4° F., or a fall of 0.5°. In the case of the control period the average initial temperature was 98.3° F., or 0.6° lower than the average for the mental work test. In spite of the fact that the initial temperature was somewhat lower than the initial temperature of the mental work test there was likewise a fall in temperature during the control period, the final temperature being 98° F. This

corresponds to a fall of 0.3°. The data also show that the body temperature was on the whole slightly higher during the mental work experiments than during the control, and that the fall in temperature during the three-hour period was slightly greater during the mental work than during the control experiment. To interpret these facts it is necessary to take into consideration the pulse rate.

### PULSE RATE.

The method of obtaining the pulse rate in these experiments is open to the objection that the subjects recorded their own pulse rates. To free the observations from as much error as possible, they were carefully instructed how to count the pulse, and to simplify the counting they were told to count a certain number of beats and register the time on a stop watch, a method which it is believed would make for accuracy. However, many of these subjects had never counted their own pulse, and it is fair to assume that there were some unavoidable errors in the observations.

The average pulse rates during both the mental and control periods are tabulated below.

*Average pulse rates.*

| Mental work experiment number. | Control experiment number. | Subject. | Pulse rate. | | Mental work experiment number. | Control experiment number. | Subject. | Pulse rate. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mental work experiments. | Control experiments. | | | | Mental work experiments. | Control experiments. |
| 1 | 23 | J. A. R. | 80 | 73 | 13 | 35 | J. N. T. | 78 | 73 |
| 2 | 24 | H. D. A. | 72 | 69 | 14 | 36 | H. C. A. | 61 | 57 |
| 3 | 25 | H. G. | 73 | 68 | 15 | 37 | F. C. B. | 82 | 79 |
| 4 | 26 | F. N. C. | 68 | 68 | 16 | 38 | G. E. H. | 70 | 59 |
| 5 | 27 | J. V. C. | 70 | 67 | 17 | 39 | N. M. P. | 63 | 65 |
| 6 | 28 | A. M., jr. | 78 | 75 | 18 | 40 | G. W. S. | 83 | 83 |
| 7 | 29 | F. E. R. | 89 | 89 | 19 | 41 | A. G. | 81 | 77 |
| 8 | 30 | J. W. H. | 83 | 70 | 20 | 42 | H. L. K. | 96 | 78 |
| 9 | 31 | C. A. R. | 76 | 93 | 21 | 43 | G. G. R. | 83 | 71 |
| 10 | 32 | G. H. H. | 117 | 89 | 22 | 44 | E. M. S. | 89 | 76 |
| 11 | 33 | H. L. W. | 79 | 73 | | | | | |
| 12 | 34 | D. R. F. | 69 | 75 | | | Average | 79 | 74 |

The average values for all the experiments show that the pulse rate was 79 during the mental work experiments as against 74 during the control, and that in only three instances was the pulse rate higher in the control than in the mental work tests. An examination of the individual experiments shows wide fluctuations. Thus the subject of experiment No. 10 showed an average pulse rate of 117 during the examination period compared with 89 during the control, while, on the other hand, the subject of experiment No. 9 showed an average pulse rate of but 76 during the mental test, as against 93 during the control.

One possible explanation of the slightly higher average pulse rate observed during the mental work tests is that these subjects had had no experience inside the respiration chamber prior to the mental work experiments, and so were nervous. Although each man entered

the chamber an hour before the experiment proper began, the pulse rate was doubtless increased as the result of the novelty of the situation. The personal impressions of the men show that they were all very much more calm at the end of the experiment than when they first entered the calorimeter.

It is not inconceivable, and, indeed, it is highly probable, that the body temperature was likewise somewhat affected by the slight excitement attending the first experience in the respiration chamber. This is, however, far from denying that there may have been sufficient excitement attending the expectation of the examination to account for the difference both in body temperature and pulse rate. Obviously, if the effect of the novelty of the situation is not considered, it is necessary to assume that the increased body temperature and pulse rate were results of the mental activity incident to the taking of a college examination.

## WATER VAPOR EXCRETED.

Water may leave the lungs and skin as water vapor, or, in the case of sensible perspiration, may leave the skin in the liquid form. It is a common popular impression that mental work frequently predisposes to profuse sensible perspiration, and, indeed, a number of subjects of these experiments were inclined to the belief that the severe mental work of examination made them perspire. In this connection a comparison of the total water vapor output is of especial interest. The comparison is made in the table following, which shows not only the total weights of water vapor eliminated, but also the water per kilogram of body weight per hour:

*Comparison of the amounts of water vapor eliminated during mental work and control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Total weight of water eliminated. | | Water eliminated per hour. | | Water eliminated per kilogram body weight per hour. | |
|---|---|---|---|---|---|---|---|---|
| | | | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. |
| | | | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Gram.* | *Gram.* |
| 1 | 23 | J. A. R. | 100.56 | 91.02 | 33.52 | 30.34 | 0.57 | 0.52 |
| 2 | 24 | H. D. A. | 133.50 | 130.91 | 44.50 | 43.64 | .68 | .65 |
| 3 | 25 | H. G. | 106.12 | 89.03 | 35.37 | 29.68 | .72 | .60 |
| 4 | 26 | F. N. C. | 111.78 | 96.25 | 37.26 | 32.08 | .64 | .56 |
| 5 | 27 | J. V. C. | 131.29 | 130.10 | 43.76 | 43.37 | .69 | .69 |
| 6 | 28 | A. M., jr. | 148.76 | 112.96 | 49.59 | 37.65 | .74 | .57 |
| 7 | 29 | F. E. R. | 119.58 | 124.53 | 39.86 | 41.51 | .77 | .79 |
| 8 | 30 | J. W. H. | 137.59 | 142.49 | 45.86 | 47.50 | .76 | .78 |
| 9 | 31 | C. A. R. | 112.78 | 118.48 | 37.59 | 39.49 | .65 | .66 |
| 10 | 32 | G. H. H. | 104.20 | 115.35 | 33.08 | 36.62 | .64 | .71 |
| 11 | 33 | H. L. W. | 123.90 | 121.00 | 41.30 | 40.33 | .80 | .78 |
| 12 | 34 | D. R. F. | 103.84 | 91.08 | 34.61 | 30.36 | .56 | .49 |
| 13 | 35 | J. N. T. | 136.71 | 105.91 | 45.57 | 35.30 | .73 | .56 |
| 14 | 36 | H. C. A. | 95.11 | 82.46 | 31.70 | 27.49 | .54 | .47 |
| 15 | 37 | F. C. B. | 170.87 | 182.03 | 44.97 | 47.90 | .62 | .64 |
| 16 | 38 | G. E. H. | 97.61 | 103.53 | 32.54 | 34.51 | .51 | .55 |
| 17 | 39 | N. M. P. | 136.45 | 107.62 | 45.48 | 35.87 | .65 | .51 |
| 18 | 40 | G. W. S. | 99.33 | 113.56 | 33.11 | 37.85 | .64 | .75 |
| 19 | 41 | A. G. | 112.26 | 130.82 | 37.42 | 43.61 | .61 | .69 |
| 20 | 42 | H. L. K. | 105.18 | 92.70 | 35.06 | 30.90 | .61 | .54 |
| 21 | 43 | G. G. R. | 127.83 | 132.63 | 42.61 | 44.21 | .54 | .57 |
| 22 | 44 | E. M. S. | 114.87 | 124.29 | 38.29 | 41.43 | .60 | .64 |
| | | Average | 119.55 | 115.40 | 39.23 | 37.80 | .65 | .62 |

From the data it is seen that on the average there were 119.55 grams of water vapor eliminated during the mental work experiments and 115.4 grams during the control experiments. It thus appears that the mental work experiments caused an increase of 4.15 grams in the water vapor leaving the body. While this is an appreciable difference, it is certainly much less than would be expected. It is important to note that in the individual experiments wide differences in the amounts of water vapor eliminated during the two periods of experiments may be found. Thus, 36 grams more water were eliminated by the subject of experiments Nos. 6 and 28 during the mental work than during the control experiment, while with the subject of experiments Nos. 19 and 41, on the other hand, 18 grams more were eliminated during the control than during the mental. On the average it would appear that the mental effort resulted in an increased elimination of water vapor amounting to 3.7 per cent. Inasmuch, however, as 45 per cent of the subjects eliminated more water in the control tests than in the mental work, the apparent value of this deduction is greatly lessened.

The marked differences in the individual experiments disappear to a slight extent when the water per kilogram of body weight per hour is computed, although the average water vapor elimination per kilogram of body weight per hour is somewhat larger during the mental work experiments than during the control.

The determinations of carbon dioxid and oxygen consumption and the nitrogenous products of the urine during mental work and control periods have been studied by other investigators. We believe that the experiments here reported represent the first instance where the water-vapor output has been accurately studied in any systematic manner in tests where sustained mental effort is one of the conditions of the experiment. In the report of the earlier experiments made in this laboratory on the effects of mental work[a] the determination of water vapor, while attempted, was extremely unsatisfactory, and indeed was not of sufficient accuracy to warrant publication.

## CARBON DIOXID EXCRETED.

As an easily determined and reasonably approximate index of changes in metabolism the carbon dioxid elimination during the mental work and the control experiments is of interest. The comparison is made in the following table.

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[a] U. S. Dept. Agr., Office of Experiment Stations Bul. 44.

*Comparison of the amounts of carbon dioxid eliminated during mental work and control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Total carbon dioxid eliminated. | | Carbon dioxid eliminated per hour. | | Carbon dioxid eliminated per kilogram of body weight per hour. | | Carbon dioxid eliminated per kilogram of body weight per minute. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. |
| | | | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Gram.* | *Gram.* | *Cc.* | *Cc.* |
| 1 | 23 | J. A. R | 101.13 | 84.51 | 33.71 | 28.17 | 0.57 | 0.48 | 4.83 | 4.06 |
| 2 | 24 | H. D. A | 94.00 | 111.99 | 31.33 | 37.33 | .48 | .56 | 4.08 | 4.72 |
| 3 | 25 | H. G | 81.94 | 83.61 | 27.31 | 27.87 | .56 | .57 | 4.71 | 4.82 |
| 4 | 26 | F. N. C | 106.09 | 97.11 | 35.36 | 32.37 | .61 | .56 | 5.19 | 4.79 |
| 5 | 27 | J. V. C | 101.60 | 97.63 | 33.87 | 32.54 | .54 | .52 | 4.55 | 4.38 |
| 6 | 28 | A. M., jr | 113.94 | 105.14 | 37.98 | 35.05 | .57 | .53 | 4.80 | 4.47 |
| 7 | 29 | F. E. R | 89.07 | 85.73 | 29.69 | 28.58 | .58 | .54 | 4.89 | 4.59 |
| 8 | 30 | J. W. H | 116.87 | 120.39 | 38.96 | 40.13 | .64 | .66 | 5.46 | 5.57 |
| 9 | 31 | C. A. R | 92.14 | 101.98 | 30.71 | 33.99 | .53 | .57 | 4.48 | 4.84 |
| 10 | 32 | G. H. H | 98.48 | 99.44 | 31.26 | 31.57 | .61 | .61 | 5.15 | 5.19 |
| 11 | 33 | H. L. W | 85.66 | 89.51 | 28.55 | 29.84 | .55 | .58 | 4.67 | 4.92 |
| 12 | 34 | D. R. F | 95.07 | 104.80 | 31.69 | 34.93 | .51 | .56 | 4.32 | 4.74 |
| 13 | 35 | J. N. T | 124.21 | 108.68 | 41.40 | 36.23 | .66 | .57 | 5.61 | 4.84 |
| 14 | 36 | H. C. A | 102.56 | 91.59 | 34.19 | 30.53 | .58 | .52 | 4.94 | 4.40 |
| 15 | 37 | F. C. B | 143.61 | 133.37 | 37.79 | 35.10 | .52 | .47 | 4.42 | 3.99 |
| 16 | 38 | G. E. H | 82.67 | 78.26 | 27.56 | 26.09 | .44 | .41 | 3.70 | 3.51 |
| 17 | 39 | N. M. P | 114.88 | 112.58 | 38.29 | 37.53 | .55 | .54 | 4.64 | 4.57 |
| 18 | 40 | G. W. S | 92.76 | 82.75 | 30.92 | 27.58 | .59 | .54 | 5.03 | 4.62 |
| 19 | 41 | A. G | 100.08 | 110.14 | 33.36 | 36.71 | .54 | .58 | 4.62 | 4.93 |
| 20 | 42 | H. L. K | 91.81 | 87.75 | 30.60 | 29.25 | .54 | .51 | 4.55 | 4.35 |
| 21 | 43 | G. G. R | 108.78 | 116.14 | 36.26 | 38.71 | .46 | .50 | 3.93 | 4.26 |
| 22 | 44 | E. M. S | 103.17 | 91.58 | 34.39 | 30.53 | .54 | .47 | 4.55 | 4.03 |
| | | Average | 101.84 | 99.76 | 33.42 | 32.76 | .55 | .54 | 4.69 | 4.57 |

While there are large differences between the two sets of experiments when individuals are considered, the average results show that 101.84 grams of carbon dioxid were excreted during the mental work experiments, while during the control experiments 99.76 grams were excreted. It thus appears that during the mental work experiments about 2 per cent more carbon dioxid was excreted than during the control experiments. For purposes of comparison the carbon dioxid per hour per kilogram of body weight per hour and the volume per kilogram of body weight per minute are likewise given, and show also the same variations as have been noted.

## OXYGEN ABSORBED.

The direct determination of the amounts of oxygen absorbed was attempted in all the experiments, but the results were unsatisfactory in eight of the twenty-two experiments, owing to the fact that it was necessary to make the experiments in quick succession, and under the circumstances less attention could be given to this factor than would otherwise be the case.

The results obtained for the oxygen consumption are given in the table which follows:

*Comparison of the amounts of oxygen absorbed during mental work and control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Total oxygen absorbed. | | Oxygen absorbed per hour. | | Oxygen absorbed per kilogram of body weight per hour. | | Oxygen absorbed per kilogram of body weight per minute. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. |
| | | | *Grams.* | *Grams.* | *Grams.* | *Grams.* | *Gram.* | *Gram* | *Cc.* | *Cc.* |
| 1 | 23 | J. A. R. | 77.04 | 62.20 | 25.68 | 20.73 | 0.43 | 0.35 | 5.06 | 4.11 |
| 2 | 24 | H. D. A. | ........ | 99.30 | ........ | 33.10 | ........ | .49 | ........ | 5.75 |
| 3 | 25 | H. G. | ........ | ........ | ........ | ........ | ........ | ........ | ........ | ........ |
| 4 | 26 | F. N. C. | 77.08 | ........ | 25.69 | ........ | .44 | ........ | 5.18 | ........ |
| 5 | 27 | J. V. C. | 88.40 | 74.00 | 29.47 | 24.67 | .47 | .39 | 5.44 | 4.57 |
| 6 | 28 | A. M., jr. | ........ | 82.04 | ........ | 27.35 | ........ | .41 | ........ | 4.80 |
| 7 | 29 | F. E. R. | 70.22 | 65.07 | 23.41 | 21.69 | .45 | .41 | 5.30 | 4.79 |
| 8 | 30 | J. W. H. | 96.70 | 97.13 | 32.23 | 32.38 | .53 | .53 | 6.21 | 6.18 |
| 9 | 31 | C. A. R. | ........ | 78.12 | ........ | 26.04 | ........ | .44 | ........ | 5.10 |
| 10 | 32 | G. H. H. | 77.95 | 90.21 | 24.75 | 28.64 | .48 | .56 | 5.60 | 6.48 |
| 11 | 33 | H. L. W. | 70.63 | 74.29 | 23.54 | 24.76 | .45 | .48 | 5.29 | 5.61 |
| 12 | 34 | D. R. F. | ........ | 78.27 | ........ | 26.09 | ........ | .42 | ........ | 4.87 |
| 13 | 35 | J. N. T. | 94.80 | 82.87 | 31.60 | 27.62 | .50 | .44 | 5.89 | 5.08 |
| 14 | 36 | H. C. A. | 74.57 | 72.67 | 24.86 | 24.22 | .42 | .41 | 4.94 | 4.79 |
| 15 | 37 | F. C. B. | 134.66 | 106.76 | 35.44 | 28.10 | .49 | .38 | 5.70 | 4.82 |
| 16 | 38 | G. E. H. | ........ | 61.82 | ........ | 20.61 | .29 | .33 | ........ | 3.81 |
| 17 | 39 | N. M. P. | 92.58 | 90.13 | 30.86 | 30.04 | .44 | .43 | 5.15 | 5.03 |
| 18 | 40 | G. W. S. | 73.19 | 65.87 | 24.40 | 21.96 | .47 | .43 | 5.46 | 5.05 |
| 19 | 41 | A. G. | 82.40 | 86.79 | 27.47 | 28.93 | .45 | .43 | 5.23 | 5.34 |
| 20 | 42 | H. L. K. | 70.25 | 71.81 | 23.42 | 23.94 | .41 | .42 | 4.79 | 4.89 |
| 21 | 43 | G. G. R. | 83.05 | ........ | 27.68 | ........ | .35 | ........ | 4.12 | ........ |
| 22 | 44 | E. M. S. | 75.35 | 72.88 | 25.12 | 24.29 | .39 | .38 | 4.57 | 4.40 |
| | | Average.. | 84.20 | 79.48 | 27.30 | 25.86 | .46 | .43 | 5.33 | 5.08 |

In the average values presented in the above table, only those experiments in which the oxygen consumption was determined during both periods are included. The results show that on the average 84.2 grams of oxygen was absorbed during the mental work period and 79.48 grams during the control period, a difference much greater than has been observed with any of the other factors thus far considered. The oxygen consumption by weight per kilogram of body weight per hour and the volume per kilogram of body weight per minute are likewise recorded in the table and emphasize the facts already pointed out. While the difference between the mental work and control experiments here indicates an increased metabolism during the mental work experiment of over 6 per cent, two facts must not be lost sight of in considering these results; first, that the figures above are the averages of 14 rather than 22 experiments, and second, that it has repeatedly been demonstrated in this laboratory that the determination of oxygen for short periods, especially when the periods are not consecutive, is extremely unsatisfactory as a basis for comparison. It would be manifestly unwise, therefore, to draw definite conclusions from the data for oxygen. The data available, however, in our opinion indicate that on an average there was a slightly increased metabolism during the mental work period.

## HEAT PRODUCTION.

The table which follows summarizes the data, showing the amounts of heat produced during the mental work and the control experiments:

*Comparison of the amounts of heat produced during mental work and control experiments.*

| Mental work experiment number. | Control experiment number. | Subject. | Total heat produced. | | Heat produced per hour. | | Heat produced per kilogram of body weight per hour. | |
|---|---|---|---|---|---|---|---|---|
| | | | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. | Mental work experiment. | Control experiment. |
| | | | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* | *Calories.* |
| 1 | 23 | J. A. R | 266.16 | 269.15 | 88.72 | 89.72 | 1.50 | 1.52 |
| 2 | 24 | H. D. A | 327.80 | 322.97 | 109.27 | 107.66 | 1.68 | 1.60 |
| 3 | 25 | H. G | 247.03 | 233.22 | 82.34 | 77.74 | 1.67 | 1.58 |
| 4 | 26 | F. N. C | 300.64 | 295.41 | 100.21 | 98.47 | 1.73 | 1.72 |
| 5 | 27 | J. V. C | 307.20 | 318.36 | 102.40 | 106.12 | 1.62 | 1.68 |
| 6 | 28 | A. M., jr | 347.03 | 293.83 | 115.68 | 97.94 | 1.72 | 1.47 |
| 7 | 29 | F. E. R | 268.39 | 295.59 | 89.46 | 98.53 | 1.74 | 1.86 |
| 8 | 30 | J. W. H | 326.40 | 340.06 | 108.80 | 113.35 | 1.80 | 1.85 |
| 9 | 31 | C. A. R | 275.82 | 292.07 | 91.94 | 97.36 | 1.58 | 1.63 |
| 10 | 32 | G. H. H | 288.44 | 280.29 | 91.57 | 88.98 | 1.78 | 1.73 |
| 11 | 33 | H. L. W | 269.65 | 284.60 | 89.88 | 94.87 | 1.73 | 1.84 |
| 12 | 34 | D. R. F | 267.43 | 268.27 | 89.14 | 89.42 | 1.43 | 1.43 |
| 13 | 35 | J. N. T | 361.21 | 313.68 | 120.40 | 104.56 | 1.92 | 1.65 |
| 14 | 36 | H. C. A | 264.99 | 282.77 | 88.33 | 94.26 | 1.50 | 1.60 |
| 15 | 37 | F. C. B | 429.00 | 409.66 | 112.89 | 107.81 | 1.56 | 1.45 |
| 16 | 38 | G. E. H | 260.79 | 247.66 | 86.93 | 82.55 | 1.37 | 1.31 |
| 17 | 39 | N. M. P | 349.67 | 343.19 | 116.56 | 114.40 | 1.67 | 1.64 |
| 18 | 40 | G. W. S | 273.21 | 253.48 | 91.07 | 84.49 | 1.75 | 1.67 |
| 19 | 41 | A. G | 281.71 | 318.12 | 93.90 | 106.04 | 1.53 | 1.68 |
| 20 | 42 | H. L. K | 283.55 | 280.43 | 94.52 | 93.48 | 1.66 | 1.64 |
| 21 | 43 | G. G. R | 329.84 | 332.55 | 109.95 | 110.85 | 1.40 | 1.44 |
| 22 | 44 | E. M. S | 298.82 | 320.45 | 99.61 | 106.82 | 1.55 | 1.66 |
| | | Average | 301.13 | 299.81 | 98.80 | 98.43 | 1.63 | 1.62 |

Since the respiration calorimeter offers a means of determining with very great accuracy the heat elimination of man, it is probably true that with the aid of these measurements the heat production can, under favorable conditions, be computed with great accuracy. The sources of error in the computations of the heat production in these particular experiments have been touched upon in the discussion of body temperature. (See p. 93.) It is believed, however, that notwithstanding these minor errors the measurements of heat production as recorded in the table above are as satisfactory as could be expected. The results show marked differences in the heat production during mental work and control experiments with certain of the subjects. But considering all the data and comparing average figures, the total heat production during the mental work experiments was on the average 301.13 calories, while during the control experiments it was 299.8 calories, or about one-half of 1 per cent less in the control than in the mental work tests.

The values for heat production per hour and per kilogram of body weight per hour are likewise included in the table. Obviously, the same percentage differences appear in these values as in those for total heat production. As a result, then, of the measurement of heat

production of twenty-two individuals during a mental work and control experiment the average results show that the heat production during the mental work period was about one-half of 1 per cent greater than during the control period, a very small amount and one which seems well within the limits of error due to small differences in the amount of muscular work in the two periods, and to other unavoidable variations in the experimental conditions.

## GENERAL CONCLUSIONS.

From the results of the data accumulated in this series of experiments on the effects of mental work on metabolism it would appear that the pulse rate was slightly increased, the body temperature somewhat higher, the water vapor output increased by about 5 per cent, the carbon dioxid production increased by about 2 per cent, the oxygen consumption increased by about 6 per cent, and the heat production increased by about one-half of 1 per cent as a result of sustained mental effort such as obtains during a college examination. Of these factors, those most accurately measured are undoubtedly the carbon dioxid elimination and the heat production. On the whole, however, the increase of both of these factors accompanying the mental exertion is so small and the exceptions are so numerous that it would not be wise to say whether or not the mental activity exercised a positive influence on metabolic processes in general. Indeed, more than half of the subjects studied produced more heat in the control than in the mental work test, which might be considered as negative evidence. This is especially so when it is considered that although every precaution was taken to eliminate all other extraneous influences it still remains a fact that, with many of these subjects, the experiments during the mental work period was their first experience inside of a complicated respiration chamber and they were more or less disturbed by the novel experience, and perhaps more restless—that is, made more muscular movements than during the control period. In view of this fact, we are very strongly of the opinion that the results obtained in these experiments do not indicate that mental effort has a positive influence on metabolic activity.

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